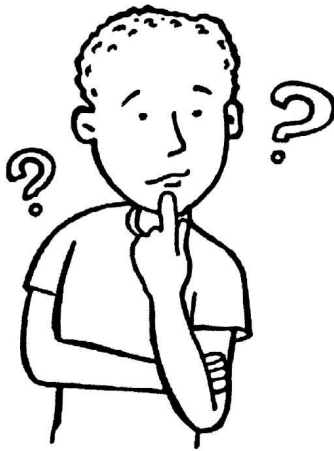


Electronics_1



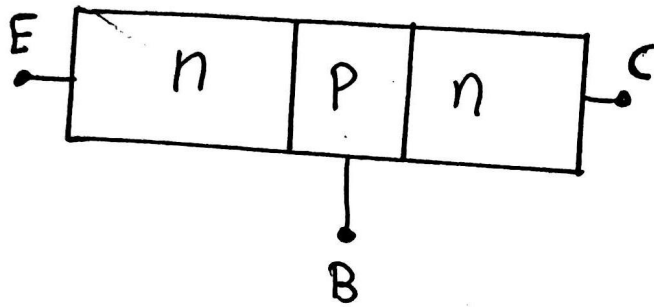
Final Revision

Part (2)

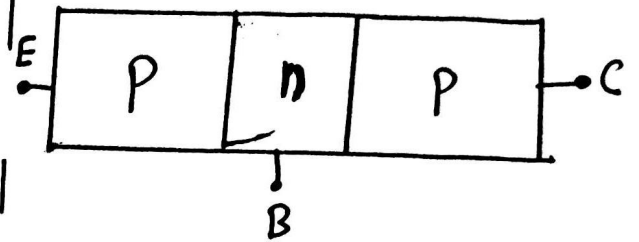
Bipolar Junction transistor

BJT

npn



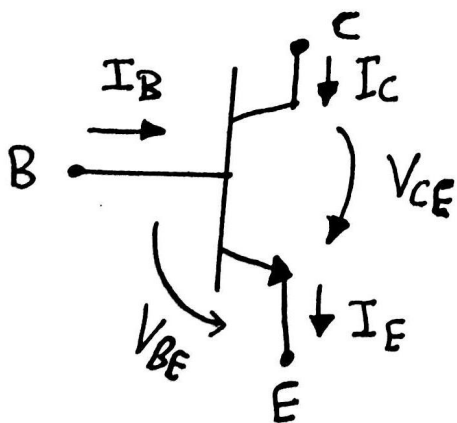
pnp



E: emitter, B: base, C: collector

* Current due to electrons.
(Diffusion)

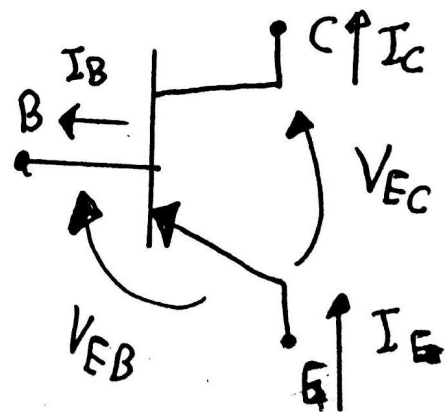
* Circuit symbol:



$$I_E = I_B + I_C$$

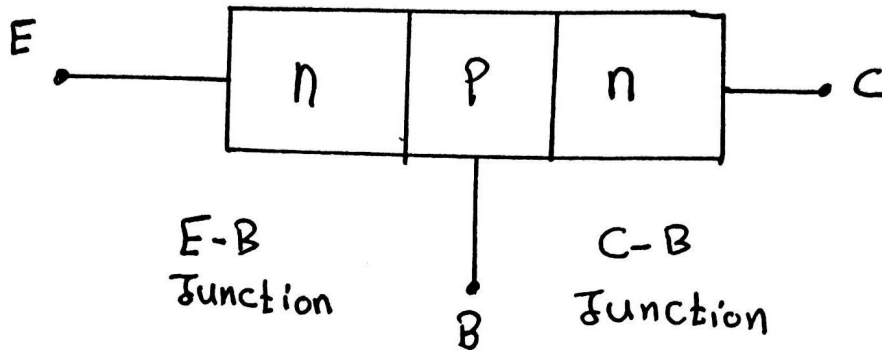
* current due to holes.
(Diffusion)

* Circuit symbol:



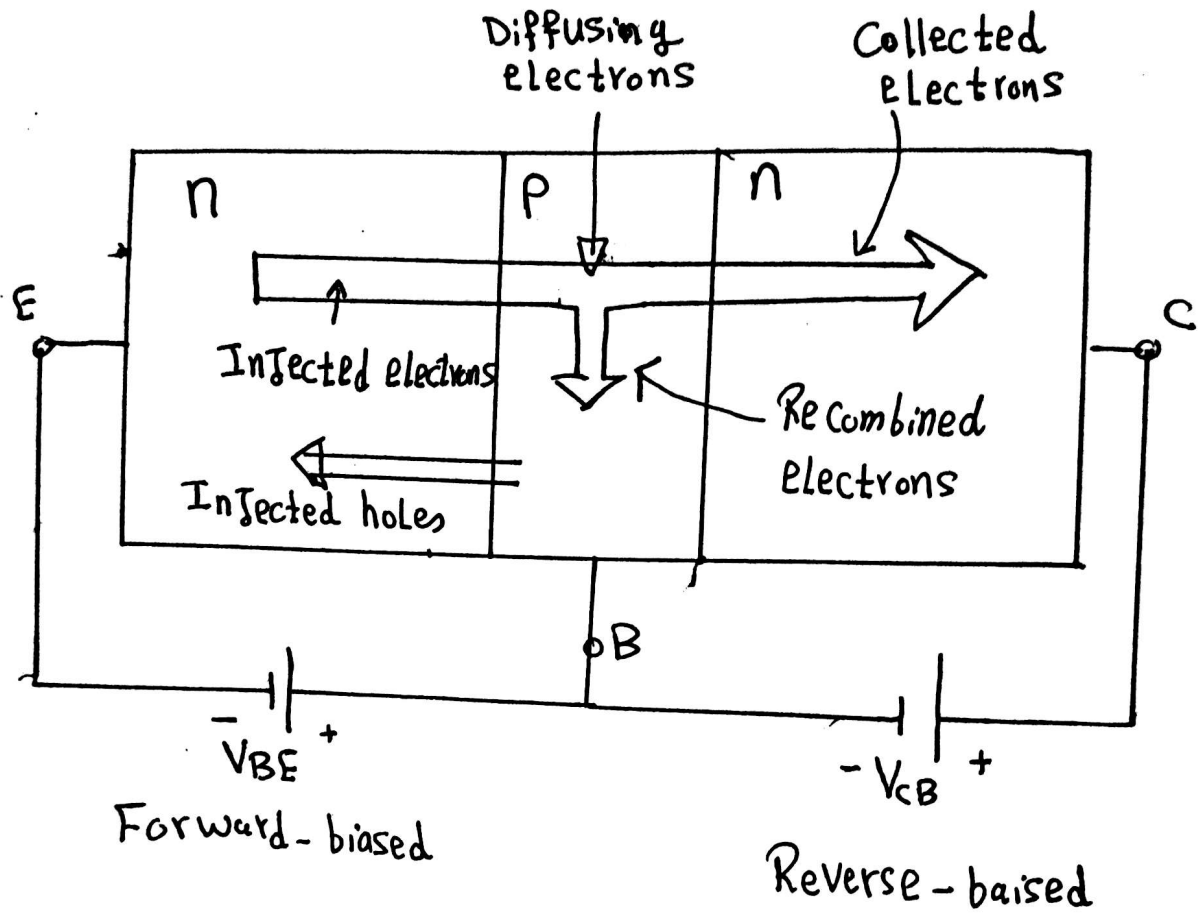
$$I_E = I_B + I_C$$

BJT modes of operation :



E-B Junction	C-B Junction	mode	Application
Forward	Reverse	Active	Amplifier
Forward	Forward	Saturation	<u>S.C</u>
Reverse	Reverse	Cut-off	<u>10-c</u>
Reverse	Forward	Inverse Active	out of this course

* EXPLAIN operation of Active mode :



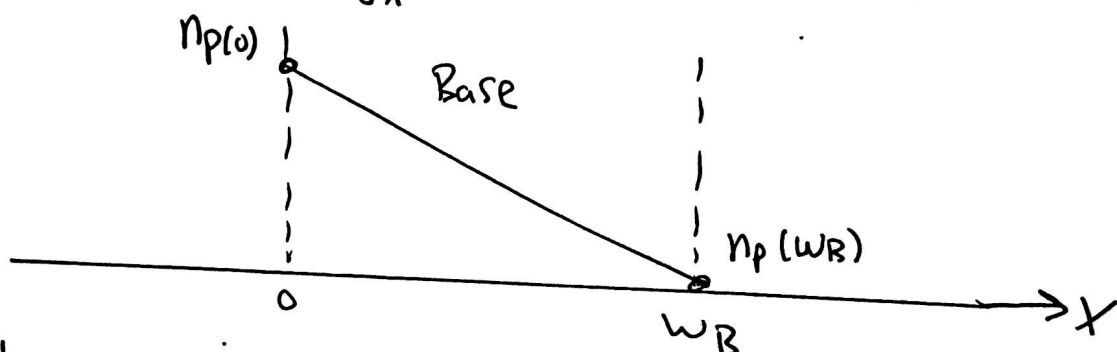
- * Electrons are injected from emitter to base.
- * These electrons move by diffusion in the base. They move from the region of high concentration near the emitter towards the region of low concentration near the collector.
- * Small number of electrons recombine at base because the base width is small.

* The C-B Junction is reverse biased, So, there is high electric field from $n \rightarrow p$. This field collects most of electrons to the collector.

* Holes are injected from base to emitter

* Proof Equation of I_C in npn BJT (23):

$$I_C = q A D_n \frac{dn_p}{dx}$$



$$\frac{dn_p}{dx} = \frac{n_p(0) - n_p(W_B)}{W_B} = \frac{n_{p0} e^{V_{BE}/V_T} - n_{p0} e^{V_{BC}/V_T}}{W_B}$$

$$\frac{dn_p}{dx} = \frac{n_{p0}}{W_B} e^{V_{BE}/V_T}, \quad n_{p0} = \frac{n_i^2}{N_A}, \quad \frac{dn_p}{dx} = \frac{n_i^2}{W_B N_A} e^{V_{BE}/V_T}$$

$$I_C = q A D_n \frac{n_i^2}{W_B N_A} e^{V_{BE}/V_T} = I_S e^{V_{BE}/V_T}$$

$$\text{Where } I_S = \frac{q A D_n n_i^2}{W_B N_A} \quad *$$

* Describe the Components of base current in npn:

1) Recombination of electrons at base

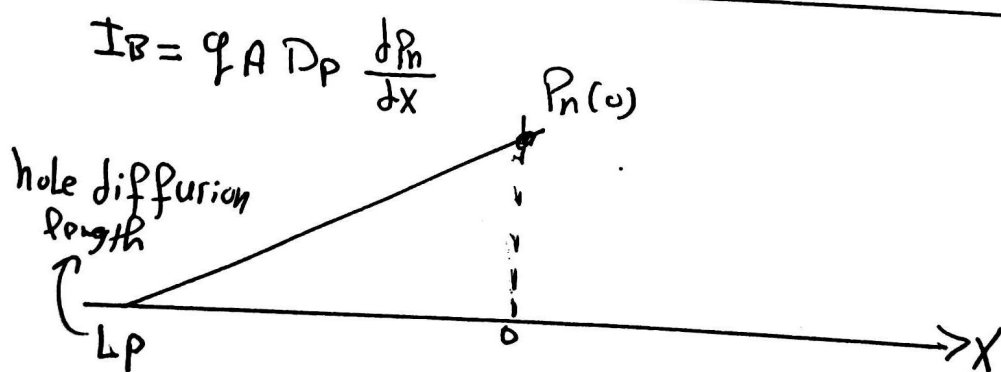
⇒ We can neglect this term if base width is small enough.

2) Injection of holes from base to emitter

So, the minority carriers at emitter increases

⇒ Diffusion current

* Proof equation of base current in npn BJT:



$$\frac{dp_n}{dx} = \frac{p_n(0)}{L_p} = \frac{p_{n0}}{L_p} e^{V_{BE}/V_T} = \frac{n_i^2}{N_D L_p} e^{V_{BE}/V_T}$$

$$I_B = q A D_p \frac{n_i^2}{N_D L_p} e^{V_{BE}/V_T}, \quad I_B = \frac{q A D_p n_i^2}{L_p N_D} e^{V_{BE}/V_T}$$

* Prove that $\beta = \frac{D_n L_P N_D}{D_p W_B N_A}$

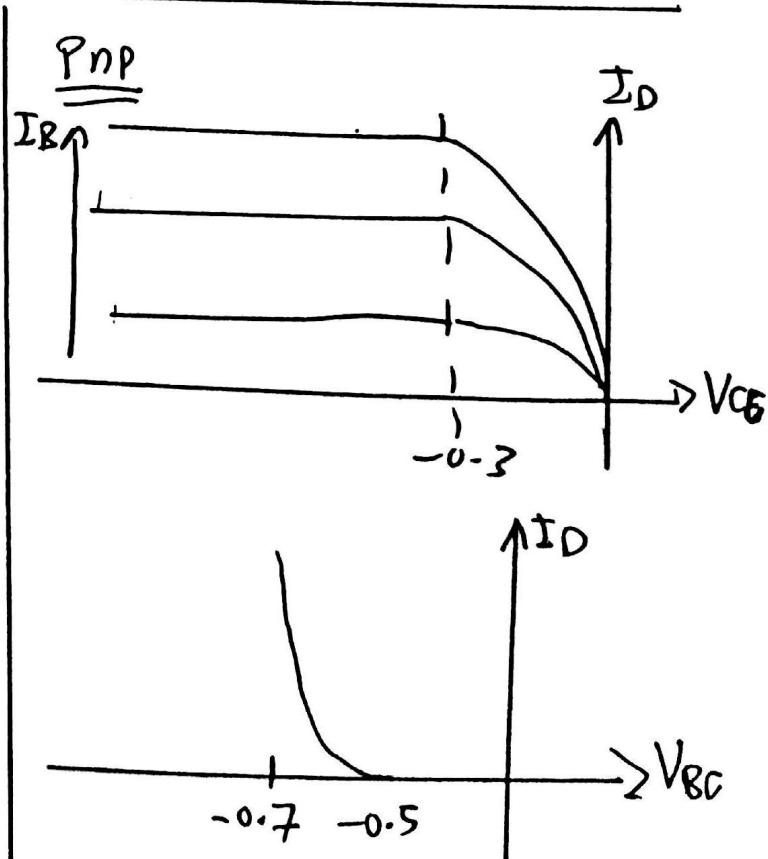
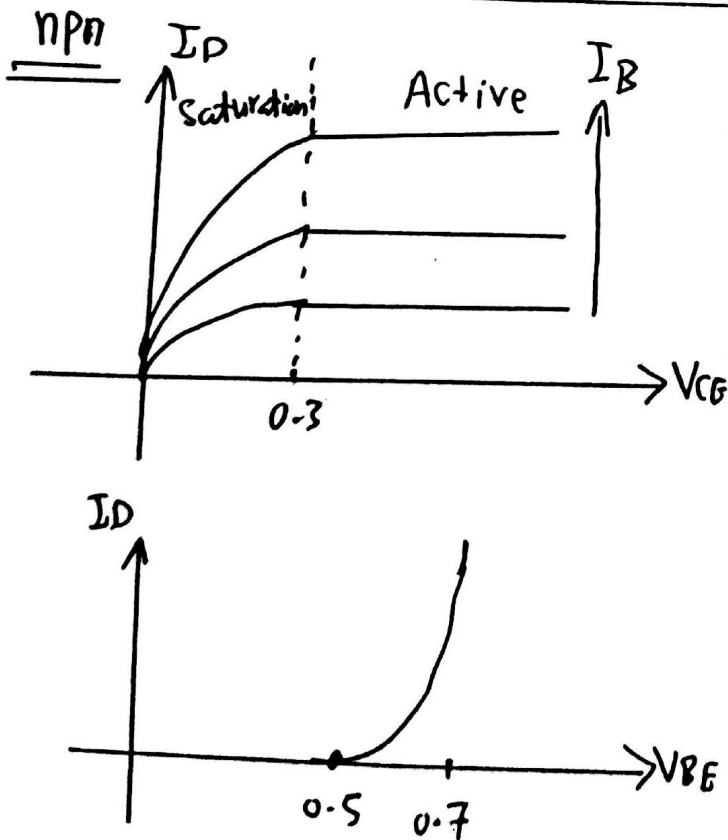
Soln

1) Prove that $I_C = \frac{q A D_n n_i^2}{W_B N_A} e^{V_{BE}/V_T}$

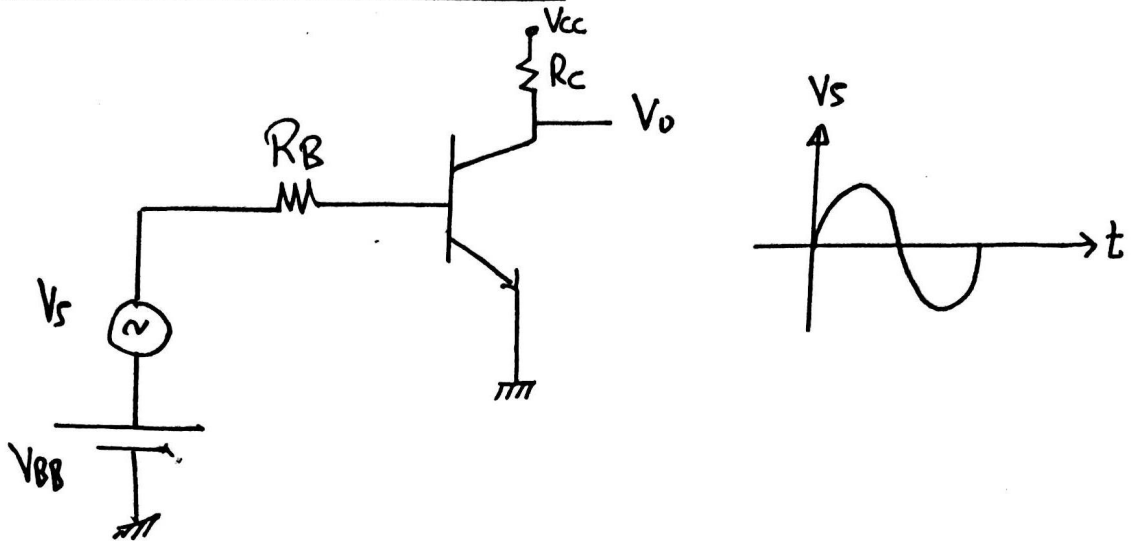
2) Prove that $I_B = \frac{q A D_p n_i^2}{L_P N_D} e^{V_{BE}/V_T}$

$\beta = \frac{I_C}{I_B} = \frac{D_n L_P N_D}{D_p W_B N_A}$ *

note $\beta = \frac{I_C}{I_B}$, $\alpha = \frac{I_C}{I_E}$, $\beta = \frac{\alpha}{1-\alpha}$, $\alpha = \frac{\beta}{1+\beta}$



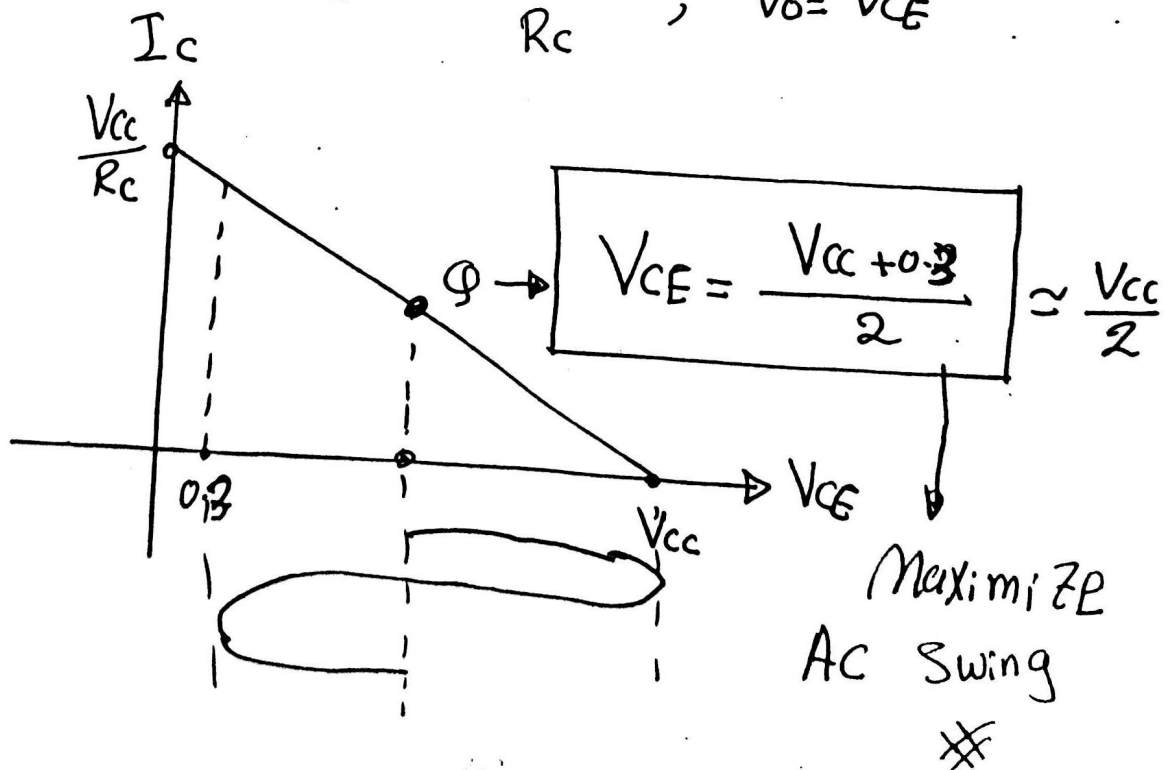
* Maximum AC Swing:



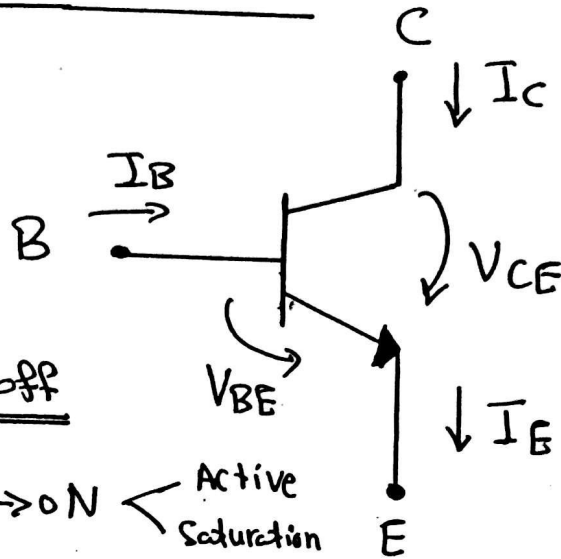
O/P KVL:

$$-V_{CC} + I_C R_C + V_{CE} = 0$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C}, \quad V_o = V_{CE}$$



* NPN BJT DC analysis



$$\beta = \infty$$

$$V_{BE} < 0.7 \Rightarrow \text{off}$$

$$V_{BE} \geq 0.7 \rightarrow \text{ON} \begin{cases} \text{Active} \\ \text{Saturation} \end{cases}$$

Assume Active

$$I_C = \beta I_B, \quad I_E = (\beta + 1) I_B, \quad V_{BE} = 0.7, \quad V_{CE} \geq 0.3$$

Check

If $V_{CE} < 0.3 \rightarrow$ Assume Saturation :

$$V_{CE} = 0.3, \quad I_E = I_C + I_B$$

$$I_C < \beta I_B \rightarrow \text{check}$$

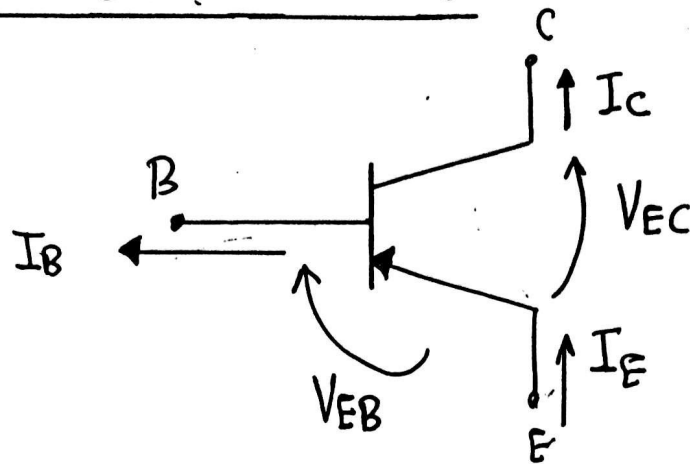
$$V_{BE} > 0.8 \rightarrow \text{Check}$$

Note: Very high β or infinite β means

$$I_B = 0$$

$$I_C = I_E$$

* PNP BJT DC analysis:



$$V_{BE} < 0.7 \text{ off}$$

$$V_{BE} \geq 0.7 \rightarrow \text{ON} \begin{cases} \text{Active} \\ \text{Saturation} \end{cases}$$

Assume Active;

$$I_C = \beta I_B, I_E = (\beta + 1) I_B, V_{BE} = 0.7, V_{EC} > 0.3$$

Check

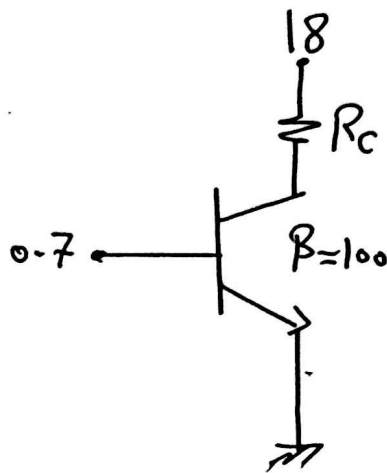
If $V_{EC} < 0.3 \rightarrow \text{assume Saturation}$

$$V_{EC} = 0.3, I_E = I_C + I_B$$

$$I_C < \beta I_B \rightarrow \text{check}$$

$$V_{BE} > 0.8 \rightarrow \text{check}$$

Pb (2,30)

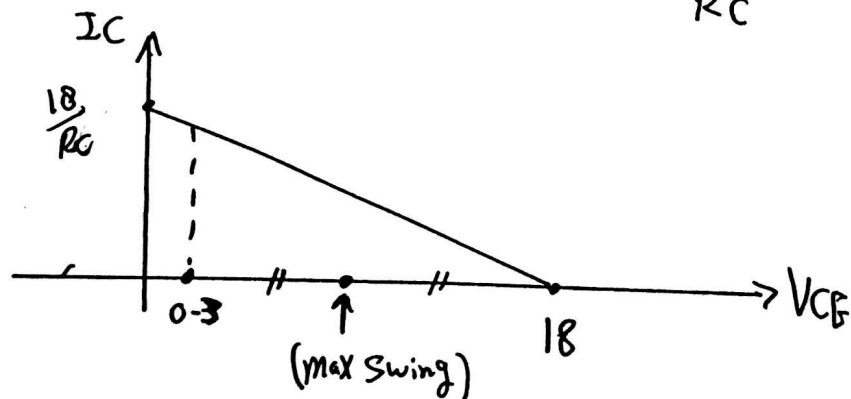


* Find R_C for maximum symmetric output swing
Given that $I_B = 100 \mu A$

Soln

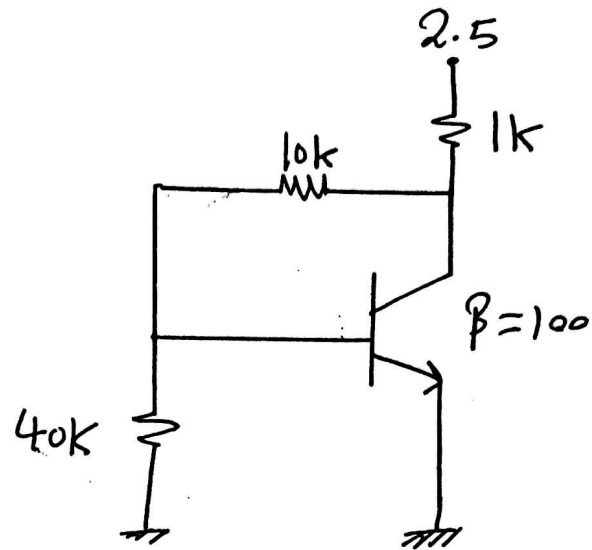
o/p KVL

$$-18 + I_C R_C + V_{CE} = 0 \longrightarrow I_C = \frac{18 - V_{CE}}{R_C}$$



$$V_{CE}|_{\text{max swing}} = \frac{18 + 0.3}{2} \approx \frac{18}{2} = 9V, \quad I_C = \beta I_B = 10 \text{ mA}$$

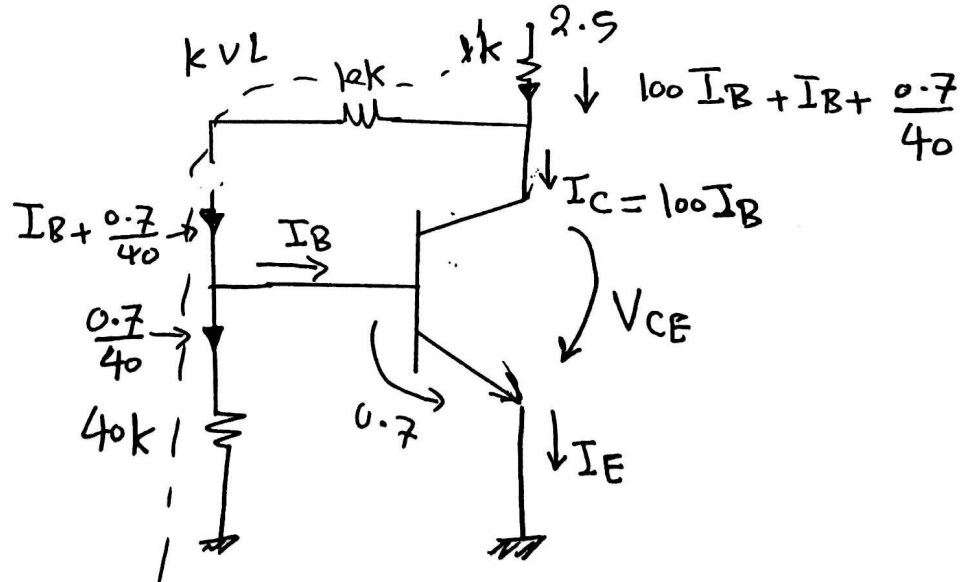
$$R_C = \frac{18 - 9}{10} = 0.9 \text{ k}\Omega \quad \#$$

P6

Find Q-Point

SolnAssume Active:

$$V_{BE} = 0.7, I_C = 100 I_B, I_E = 101 I_B, V_{CE} > 0.3$$



KVL :

$$-2.5 + (101 I_B + \frac{0.7}{40})(1) + (I_B + \frac{0.7}{40})(10) + 0.7 = 0$$

$$I_B = 14.48 \mu A$$

$$I_C = 1.448 \text{ mA}$$

$$I_E = 1.4626 \text{ mA}$$

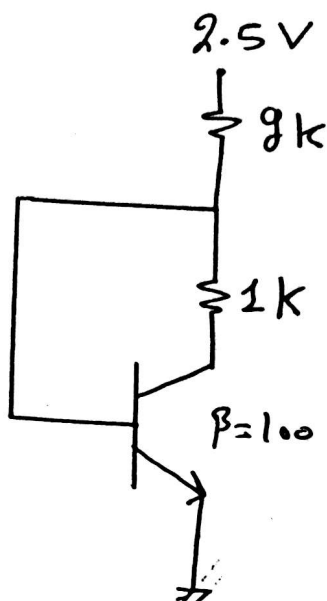
o/p KVL :

$$-2.5 + (101 (14.48 \mu A) + \frac{0.7}{40}) + V_{CE} = 0$$

$$\therefore V_{CE} = 1.02 \text{ V} > 0.3 \Rightarrow \text{Active}$$

$$Q\text{-Point } (I_C = 1.448 \text{ mA}, V_{CE} = 1.02 \text{ V})$$

$$(I_B = 14.48 \mu A, V_{BE} = 0.7 \text{ V})$$

P6

Find Q-point

Solnassume active :

$$I_C = 100 I_B, V_{BE} = 0.7$$

$$V_{CE} > 0.3$$

B-E KVL

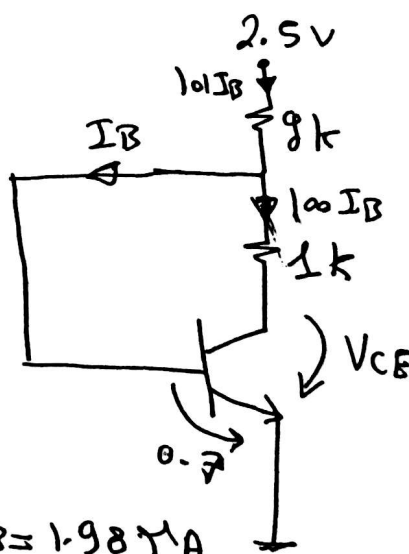
$$-2.5 + 101 I_B \times 9 + 0.7 = 0 \Rightarrow I_B = 1.98 \mu A$$

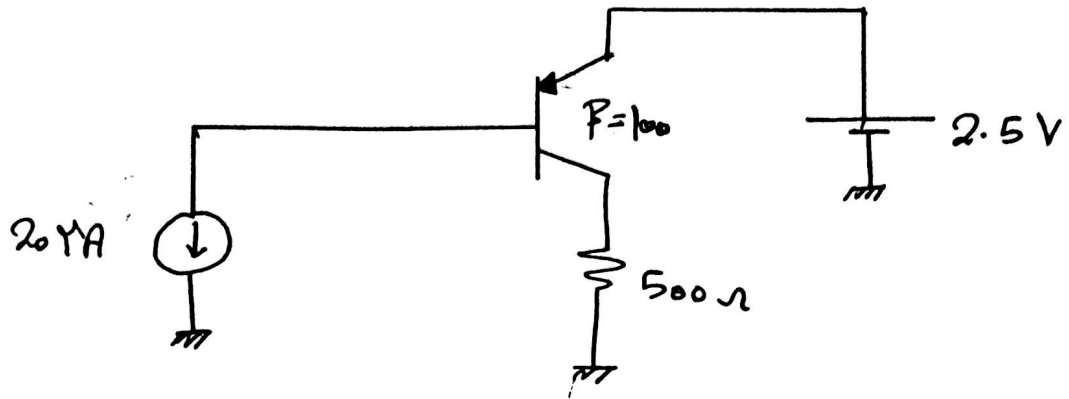
C-P KVL!

$$-2.5 + 101(1.98 \times 10^{-6}) \times 9 + 100(1.98 \times 10^{-6}) + V_{CE} = 0$$

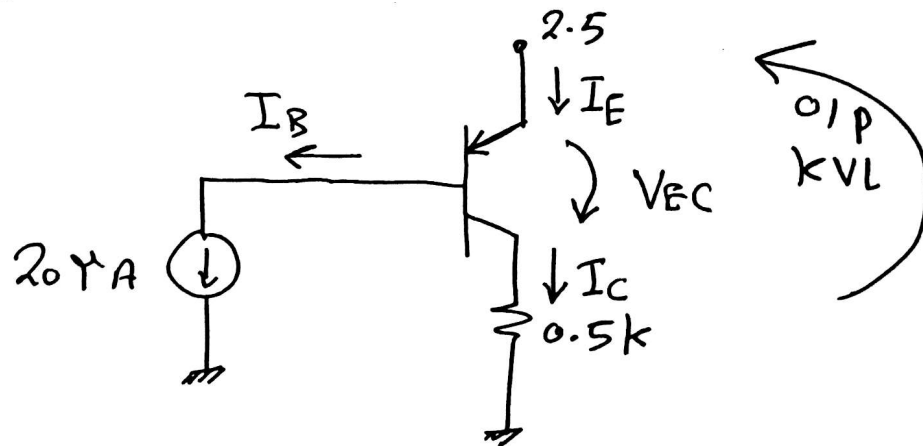
$$V_{CE} = 0.5 > 0.3 \Rightarrow \text{Active} \quad I_C = 0.198 \text{ mA}$$

*



P6

Find Q-Point & Determine mode of operation.

Soln

Assume Active

$$I_C = 100 I_B, V_{EB} = 0.7, V_{EC} > 0.3$$

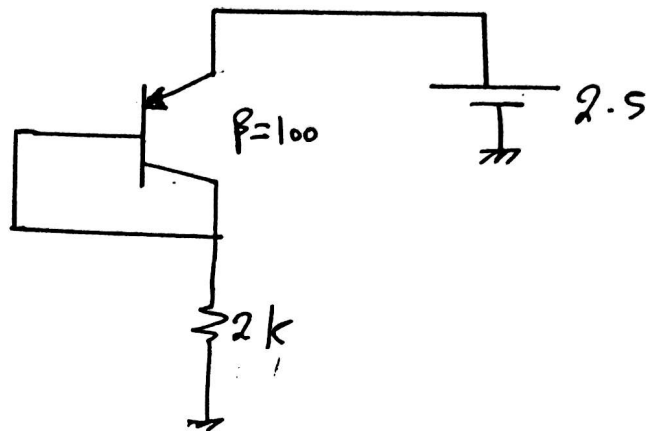
$$I_C = 100 \times 20 \mu A = 2 \text{ mA}$$

o/p KVL: $-2.5 + V_{EC} + 0.5(2) = 0$

$$V_{EC} = 1.5 > 0.3 \Rightarrow \text{Active}$$

Q-Point ($I_C = 2\text{mA}$, $V_{EC} = 1.5\text{V}$)
 ($I_B = 20\mu\text{A}$, $V_{EB} = 0.7$)

Pb



Find Q-Point

Soln

$$V_{EC} = V_{EB} = 0.7 > 0.3 \Rightarrow \text{Active}$$

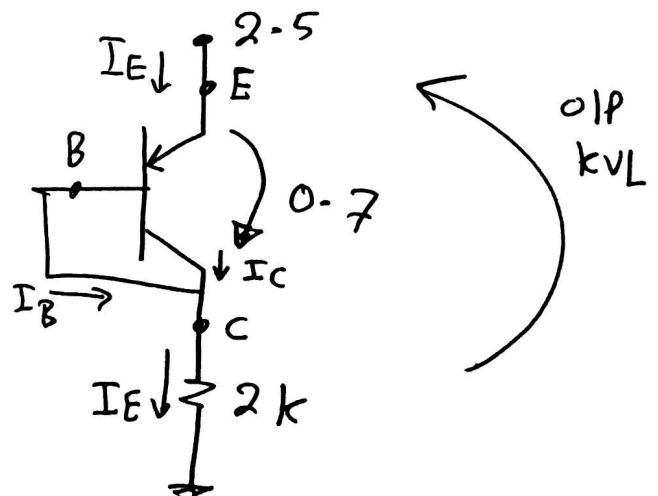
o/p KVL :

$$-2.5 + 0.7 + 2 I_E = 0$$

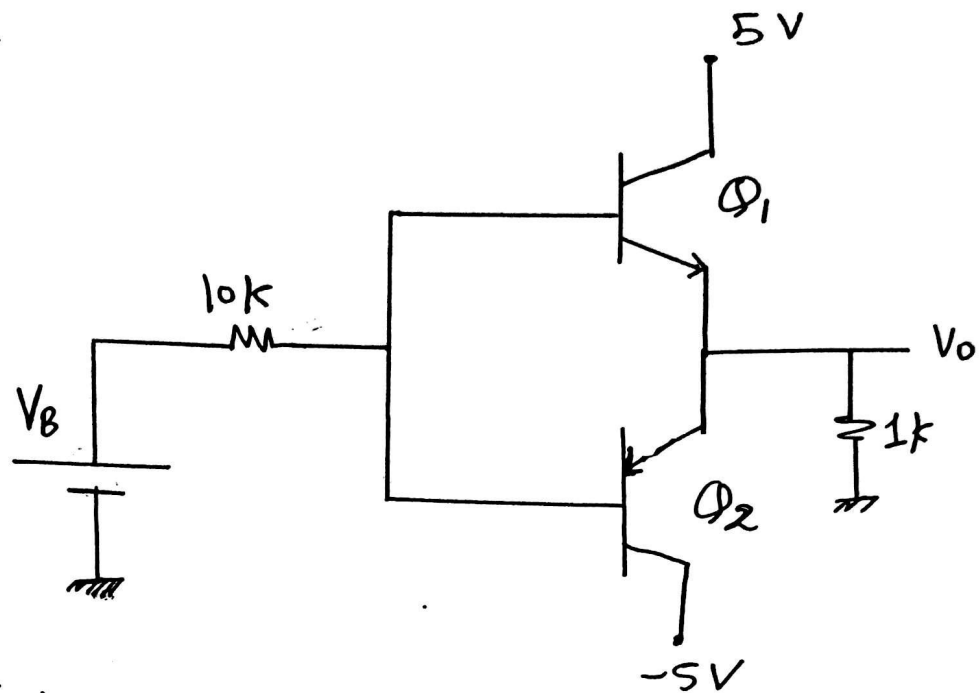
$$I_E = 0.9\text{mA}$$

$$I_C = \frac{\beta}{1+\beta} I_E$$

$$I_C = 0.89\text{mA}$$



Q-point ($I_C = 0.89\text{mA}$, $V_{EC} = 0.7\text{V}$)
 ($I_B = 8.9\mu\text{A}$, $V_{EB} = 0.7\text{V}$)

P6

Find $V_O = ?$ if $V_B = 0V, 5V, -5V$, $\beta = 100$

Soln Note $V_{BE1} = V_{BE2}$

Q_1 to be ON needs $V_{BE1} = 0.7 \rightarrow$ npn

Q_2 to be ON needs $V_{BE2} = -0.7 \rightarrow$ pnp

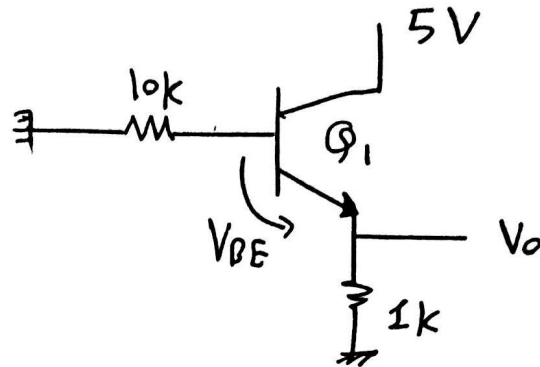
So, Q_1 and Q_2 Cannot be ON at the same time

* We have three Conditions

- $\rightarrow Q_1 : \text{ON} \ \& \ Q_2 : \text{OFF}$
- $\rightarrow Q_1 : \text{OFF} \ \& \ Q_2 : \text{ON}$
- $\rightarrow Q_1 : \text{OFF} \ \& \ Q_2 : \text{OFF}$

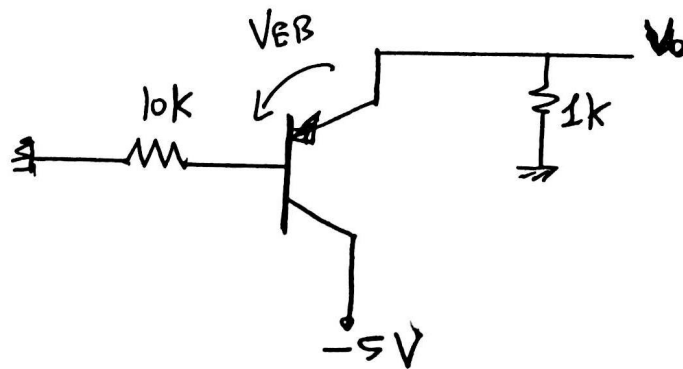
$V_B = 0$:

assume ϕ_1 : ON & ϕ_2 : OFF



V_{BE} Cannot be 0.7 $\longrightarrow \phi_1$ must be OFF
 $\Rightarrow \phi_1$: ON & ϕ_2 : OFF (Wrong Condition)

assume ϕ_1 : OFF & ϕ_2 : ON

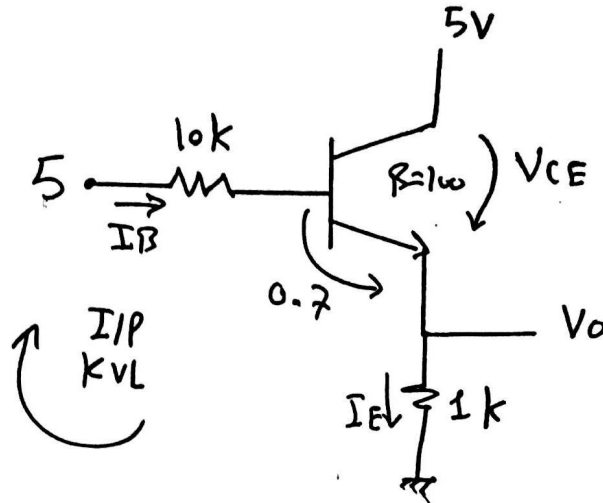


V_{EB} Cannot be 0.7 $\Rightarrow \phi_2$ must be OFF
 $\Rightarrow \phi_1$: OFF & ϕ_2 : ON (Wrong)

When $V_B = 0 \Rightarrow \phi_1$: OFF & ϕ_2 : OFF $\Rightarrow (V_O = \text{Zero})$

$$\underline{V_B = 5V}$$

$Q_1: \text{ON} \ \& \ Q_2: \text{OFF}$



assume active!

$$V_{BE} = 0.7, \ I_C = 100 I_B, \ I_E = 101 I_B$$

I/P KVL:

$$-5 + 10 I_B + 0.7 + 101 I_B = 0$$

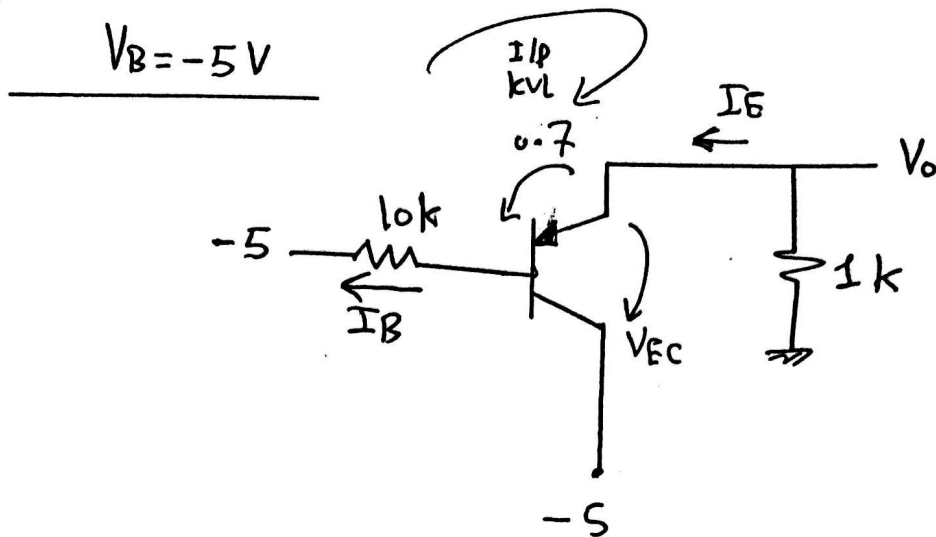
$$I_B = 38.7 \mu A, \ I_C = 3.87 \text{ mA}, \ I_E = 3.9 \text{ mA}$$

$$V_O = I_E(1) = 3.9 \text{ V}$$

O/P KVL: check

$$-5 + V_{CE} + 3.9 = 0 \Rightarrow V_{CE} = 1.1 > 0.3$$

Active ✓



Assume active!

$$V_{BE} = 0.7, I_C = 100 I_B, I_E = 101 I_B, V_{EC} > 0.3$$

I/P KVL:

$$I_E + 0.7 + 10 I_B - 5 = 0$$

$$101 I_B + 0.7 + 10 I_B - 5 = 0 \rightarrow I_B = 38.7 \mu A$$

$$I_E = 3.9 \text{ mA}$$

O/P KVL

$$I_E + V_{EC} - 5 = 0$$

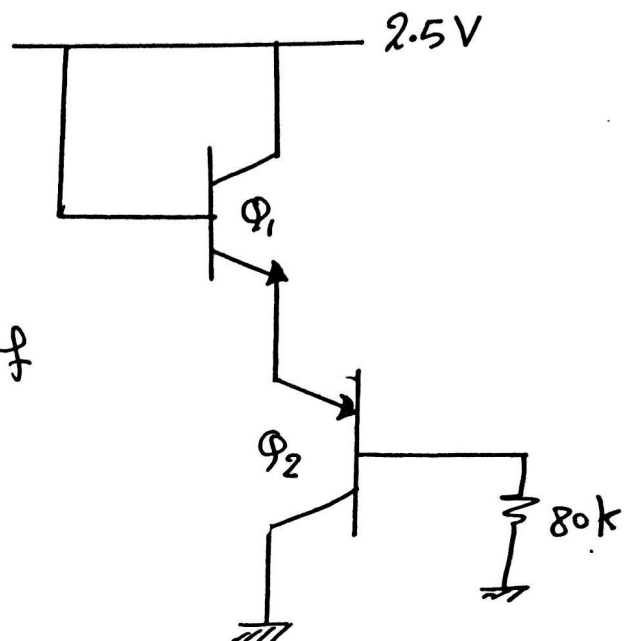
$$V_{EC} = 1.1 > 0.3 \Rightarrow \text{Active}$$

$$V_O = -3.9 \text{ V}$$

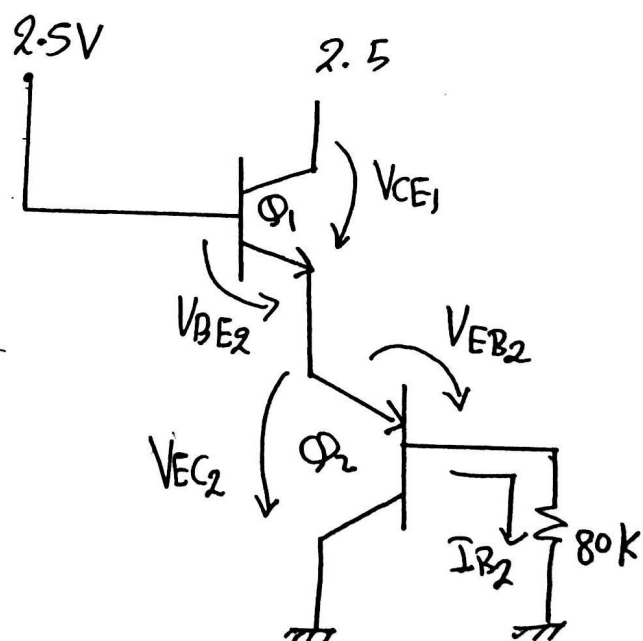
P6

$$\beta = 100$$

Find operating point of Q_1 & Q_2



soln



$$\Phi_1 \Rightarrow V_{BE1} = V_{CE1} \Rightarrow \text{Active}$$

assume Φ_2 is active

$$\begin{aligned} & \swarrow V_{BE1} = 0.7 \\ & \searrow I_{C1} = \beta I_{B1} \\ & \quad I_{E1} = (\beta + 1) I_{B1} \end{aligned}$$

$$V_{EB2} = 0.7, \quad I_{C2} = \beta I_{B2}, \quad I_{E2} = (\beta + 1) I_{B2}$$

From circuit $\longrightarrow I_{E1} = I_{E2}$

$$\downarrow$$

$$I_{C1} = I_{C2} \longrightarrow I_{B1} = I_{B2}$$

B-E KVL:

$$-2.5 + V_{BE1} + V_{EB2} + 80 I_{B2} = 0$$

$$-2.5 + 0.7 + 0.7 + 80 I_{B2} = 0 \longrightarrow I_{B2} = 13.75 \mu A$$

$$I_{B1} = I_{B2} = 13.75 \mu A, \quad I_{C1} = I_{C2} = 1.375 \text{ mA}$$

C-E KVL:

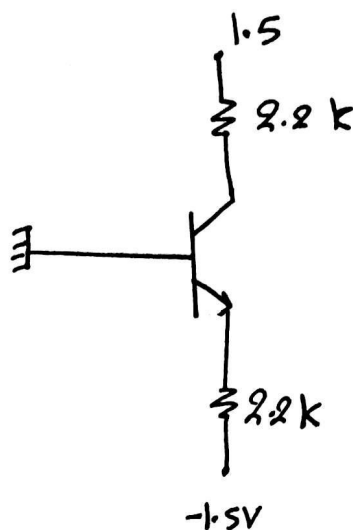
$$-2.5 + V_{CE1} + V_{EC2} = 0 \Rightarrow V_{EC2} = 2.5 - 0.7 = 1.8 \text{ V} > 0.3$$

\downarrow
Active

Φ_1 -Point $(I_{C1} = 1.375 \text{ mA}, V_{CE1} = 0.7 \text{ V})$
 $(I_{B1} = 13.75 \mu A, V_{BE1} = 0.7 \text{ V})$

Φ_2 -Point $(I_{C2} = 1.375 \text{ mA}, V_{EC2} = 1.8 \text{ V})$
 $(I_{B2} = 13.75 \mu A, V_{EB2} = 0.7 \text{ V})$ #

Pb(1), Sheet(4)



Find the emitter, base and collector Voltages and Currents, $\beta = 50$.

Soln

assume Active

- 1) $I_C = \beta I_B = 50 I_B$
- 2) $I_E = (\beta + 1) I_B = 51 I_B$
- 3) $V_{BE} = 0.7$
- 4) $V_{CE} > 0.3$

I/P KVL:

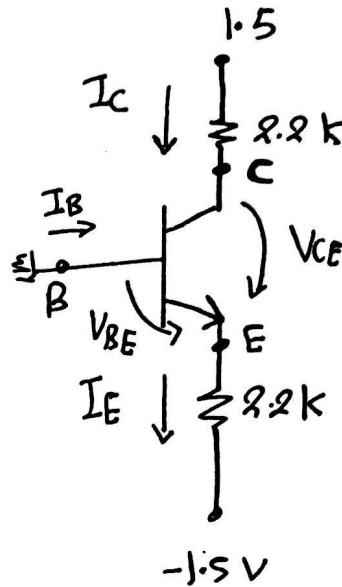
$$V_{BE} + 2.2 I_E - 1.5 = 0$$

$$0.7 + 2.2 \times 51 I_B - 1.5 = 0$$

$$I_B = 7.13 \mu A$$

$$I_C = 50 I_B = 0.356 \text{ mA}$$

$$I_E = 51 I_B = 0.364 \text{ mA}$$



O/P KVL:

$$-1.5 + 2.2 I_C + V_{CE} + 2.2 I_E - 1.5 = 0$$

$$V_{CE} = 3 - 2.2(0.356) - 2.2(0.364) = 1.416 \text{ Volt}$$

$$\therefore V_{CE} > 0.3 \Rightarrow \text{True assumption.}$$

$$V_B = 0 \Rightarrow V_{BE} = 0.7 \Rightarrow V_E = -0.7$$

$$V_{CE} = V_C - V_E = V_C + 0.7 = 1.416 \Rightarrow V_C = 0.716$$

$$I_B = 7.13 \mu A$$

$$I_C = 0.356 \text{ mA}$$

$$I_E = 0.364 \text{ mA}$$

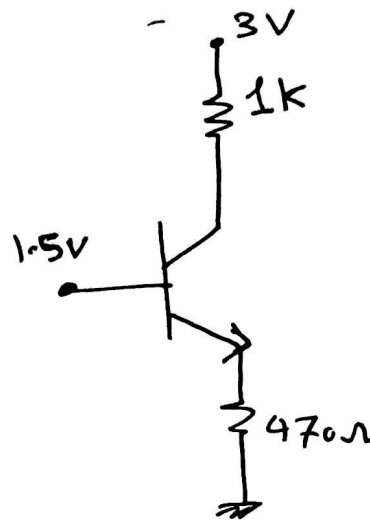
$$V_B = 0$$

$$V_E = -0.7$$

$$V_C = 0.716$$

Pb2 (Sheet 4)

Find all currents &
Voltages $\Rightarrow \beta = 50$



Sohn

assume Active

- 1) $I_C = \beta I_B = 50 I_B$
- 2) $I_E = (\beta + 1) I_B = 51 I_B$
- 3) $V_{BE} = 0.7$
- 4) $V_{CE} > 0.3$

I/P KVL

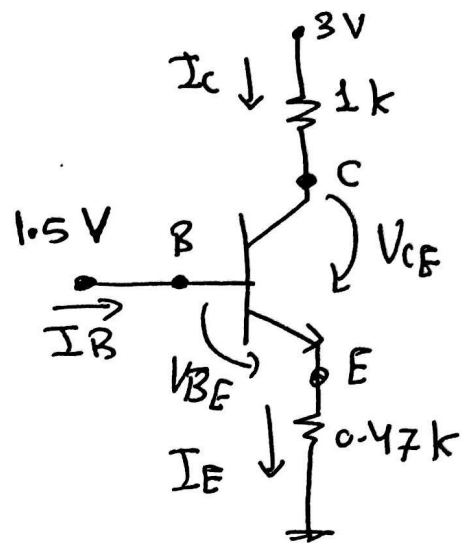
$$-1.5 + V_{BE} + 0.47 \times I_E = 0$$

$$-1.5 + 0.7 + 0.47 \times 51 I_B = 0$$

$$I_B = 33.375 \mu A$$

$$I_C = 1.67 \text{ mA}$$

$$I_E = 1.7 \text{ mA}$$

O/P KVL

$$-3 + I_C + V_{CE} + 0.47 I_E = 0$$

$$V_{CE} = 3 - 1.67 - 0.47 \times (1.7) = 0.531$$

$\therefore V_{CE} > 0.3 \Rightarrow$ True assumption

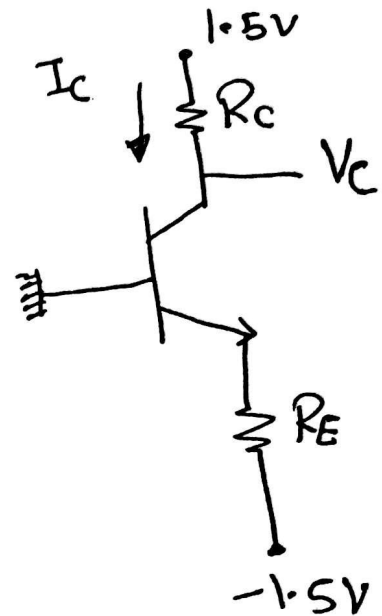
$$V_B = 1.5 \text{ V}, \quad V_{BE} = V_B - V_E = 1.5 - V_E = 0.7$$

$$V_E = 0.8 \text{ V}, \quad V_{CE} = V_C - V_E = V_C - 0.8 = 0.531$$

$$\therefore V_C = 1.331 \text{ Volt}$$

Pb3 (Sheet 4)

Design the circuit to
establish $I_C = 0.1 \text{ mA}$, $V_C = 0.5 \text{ V}$
 $\beta = 100$



Note $V_C = 0.5 \text{ V}$

* Assume Active $\Rightarrow V_{BE} = 0.7 \Rightarrow V_E = -0.7$

$\therefore V_{CE} = 0.5 + 0.7 = 1.2 > 0.3 \Rightarrow$ True assumption

$$R_C = \frac{1.5 - 0.5}{0.1} = 10 \text{ k}\Omega$$

$$I_E = I_C + I_B = I_C + \frac{I_C}{\beta} = \left(1 + \frac{1}{\beta}\right) I_C$$

$$I_E = (1 + 0.01) \times 0.1 = 0.101 \text{ mA}$$

$$R_E = \frac{-0.7 - (-1.5)}{0.101} = 7.9 \text{ k}\Omega$$

Pb (4) Sheet (4)

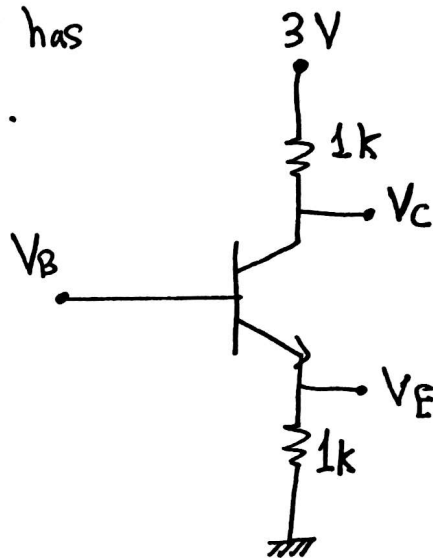
The transistor has
Very high β .

Find V_E, V_C ?
for

(a) $V_B = 1.5 \text{ V}$

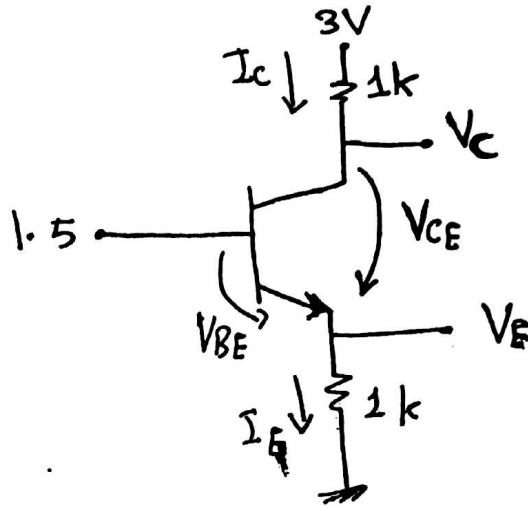
(b) $V_B = 1 \text{ V}$

(c) $V_B = 0 \text{ V}$



at very high $\beta \Rightarrow I_B = 0, I_C = I_E$

a) $V_B = 1.5V$



assume Active:

* $V_{BE} = 0.7, V_{CE} > 0.3$

I/P KVL

$$-1.5 + V_{BE} + I_E = 0 \Rightarrow -1.5 + 0.7 + I_E = 0$$

$\therefore I_E = 0.8 \text{ mA}, I_C = I_E = 0.8 \text{ mA}$

O/P KVL

$$-3 + I_C + V_{CE} + I_E = 0 \Rightarrow V_{CE} = 1.4 > 0.3 \quad \checkmark$$

$$V_{BE} = 1.5 - V_E = 0.7 \Rightarrow V_E = 0.8 \text{ Volt}$$

$$V_{CE} = V_C - V_E = V_C - 0.8 = 1.4 \Rightarrow V_C = 2.2 \text{ Volt} \quad \checkmark$$

b) For $V_B = 1V$ Same as the previous case
start from I/P KVL

I/P KVL:

$$-1 + V_{BE} + I_E = 0 \Rightarrow I_E = 0.3 \text{ mA}$$

$$I_C = I_E = 0.3 \text{ mA}$$

O/P KVL

$$V_{CE} = 3 - I_C - I_E = 2.4 > 0.3 \Rightarrow \text{✓}$$

$$V_C = 3 - 0.3 = 2.7, \quad V_E = 0.3.$$

c) For $V_B = 0 \text{ Volt}$

$$I_E = I_B = I_C = 0, \quad V_C = 3 \text{ Volt}, \quad V_E = \text{Zero Volt}$$

So, we can conclude as V_B decreases.

$$V_C \uparrow, \quad V_E \downarrow$$

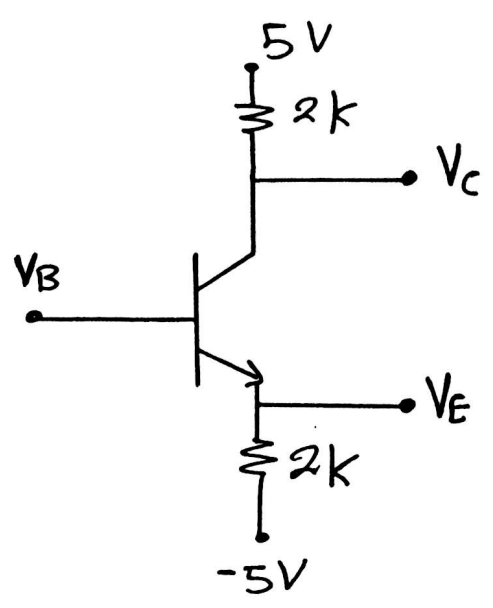
Pb5 (Sheet3) :

* β Very high
 (i) Find V_C and $V_E = ?$

a) $V_B = -1V$

b) $V_B = 0V$

c) $V_B = 1V$



Soln

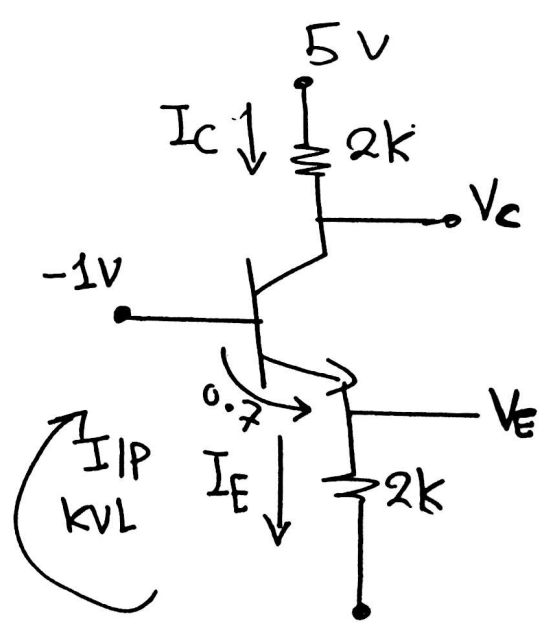
a) $V_B = -1V$

* $I_C = I_E$

* Assume Active

$$V_{BE} = 0.7, V_{CE} > 0.3$$

I/P KVL



$$1 + 0.7 + 2 I_E - 5 = 0 \rightarrow I_E = 1.65 \text{ mA}$$

$$I_E = I_C = 1.65 \text{ mA}$$

$$V_C = 5 - 2 I_C = 5 - 2(1.65) = 1.7 \text{ Volt}$$

$$V_E = -1 - 0.7 = -1.7$$

$$V_{CE} = V_C - V_E = 3.4 > 0.3 \Rightarrow \text{True assumption}$$

$$\underline{b) V_B = 0V}$$

$$\underline{\text{I/P KVL}} \quad 0.7 + 2 I_E - 5 = 0 \longrightarrow I_E = I_C = 2.15 \text{ mA}$$

$$V_C = 5 - 2(2.15) = 0.7$$

$$V_E = 0 - 0.7 = -0.7$$

$$V_{CE} = 1.4 > 0.3 \longrightarrow \text{Active}$$

$$\underline{c) V_B = 1V :}$$

$$\underline{\text{I/P KVL}} : -1 + 0.7 + 2 I_E - 5 = 0 \Rightarrow I_E = 2.65 \text{ mA} = I_C$$

$$V_C = 5 - 2(2.65) = -0.3 \text{ V.}$$

$$V_E = 1 - 0.7 = 0.3 \text{ V}$$

$$V_{CE} = -0.6 < 0.3 \Rightarrow \text{not active } X$$

Now, assume saturation

$$V_{CE} = 0.3$$

O/P KVL :

$$-5 + 2I_C + 0.3 + 2I_C - 5 = 0 \rightarrow I_C = 2.425 \text{ mA}$$

$$V_C = 5 - 2(2.425) = 0.15 \text{ V}$$

$$V_E = -0.15 \text{ V}$$

$$V_{BE} = 1 - (-0.15) = 1.15 > 0.8 \Rightarrow \text{True assumption}$$

(ii) Find $V_B = ?$ such that $I_E|_{V_B} = \frac{I_E}{V_{B50}}|_{V_{B50}}$

Soln $V_{B20} \text{ V} \rightarrow I_E = 2.15 \text{ mA}$

$$I_E|_{V_B} = 0.215 \text{ mA}$$

O/P KVL : $-5 + 2(0.215) + V_{CE} + 2(0.215) - 5 = 0$

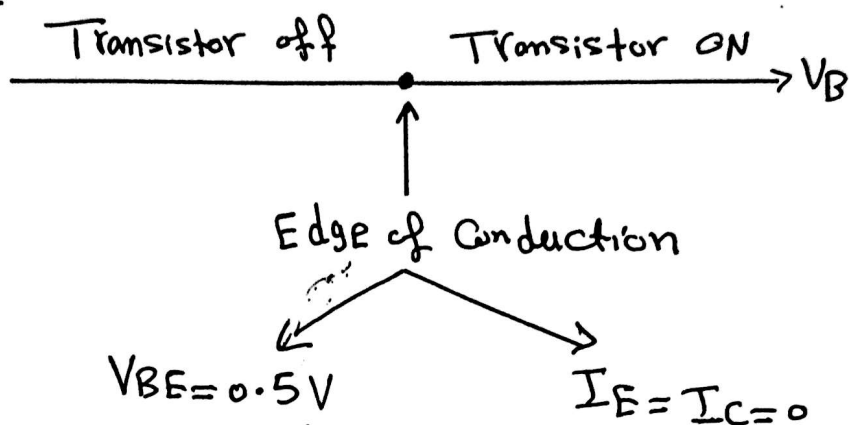
$$V_{CE} = 9.14 > 0.3 \Rightarrow \text{Active}$$

$$V_{BE} = 0.7 \Rightarrow V_B = V_E + 0.7 = 2(0.215) - 5 + 0.7$$

$$\boxed{V_B = -3.87 \text{ V}}$$

$V_B = ? \longrightarrow$ Transistor at the edge of Conduction
then find V_E & $V_C = ?$

Soln



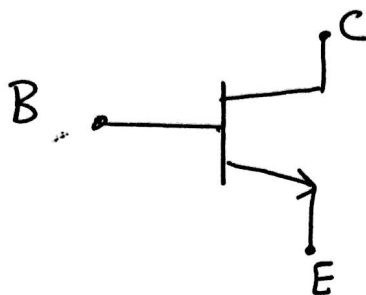
I/P KVL:

$$-V_B + 0.5 - 5 = 0 \longrightarrow V_B = 4.5 \text{ V}$$

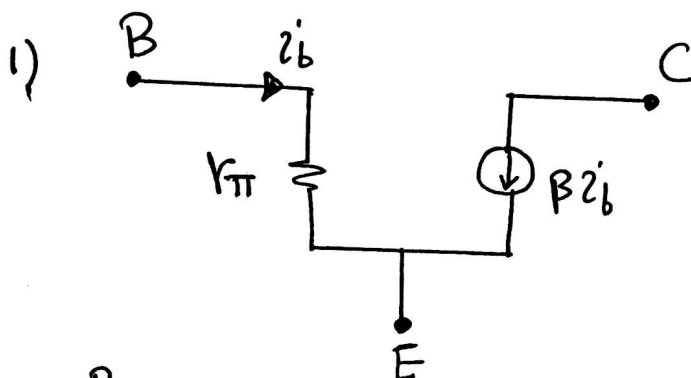
$$V_C = 5 \text{ V}$$

$$V_E = -5 \text{ V}$$

* BJT Small signal model :

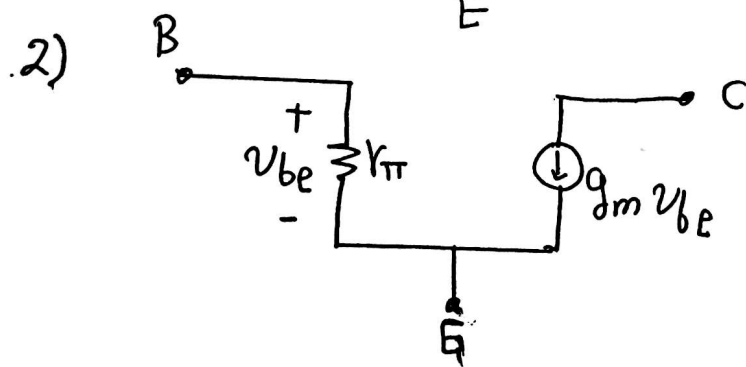


There is three models !



$$r_{\pi} = \frac{V_T}{I_B} = \frac{\beta V_T}{I_C}$$

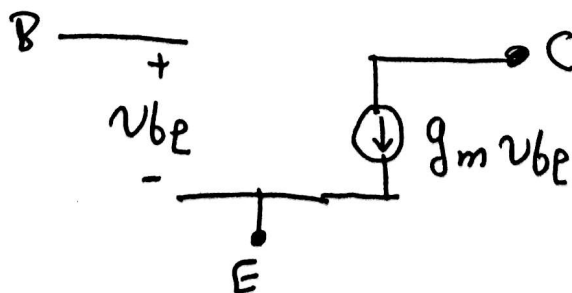
DC analysis



$$g_m = \frac{\beta}{r_{\pi}} = \frac{I_C}{V_T}$$

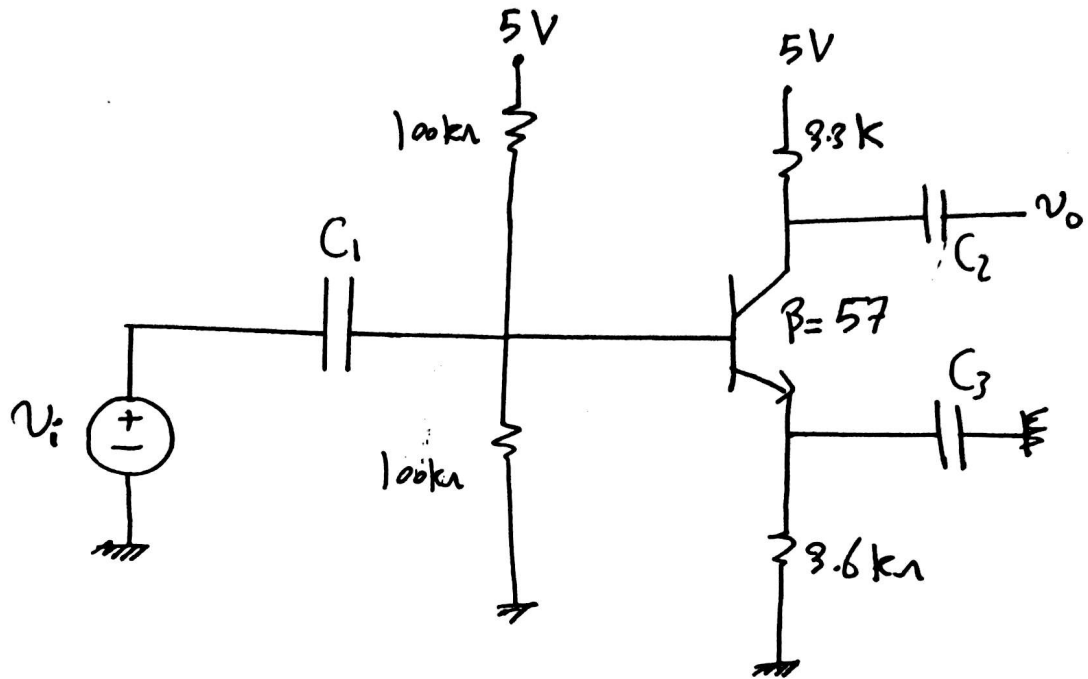
26mV

3) β Very Large or infinity



$$g_m = \frac{\beta}{r_{\pi}} = \frac{I_C}{V_T}$$

Pb6 (Sheet 4)

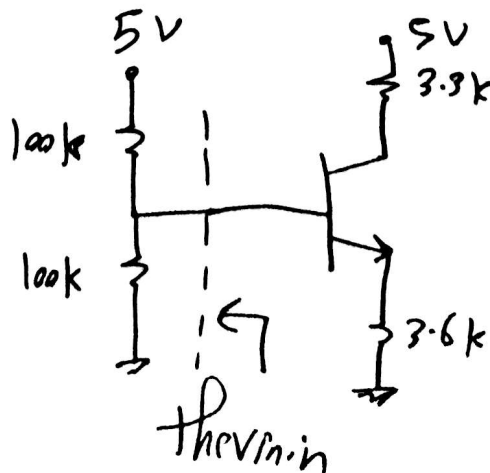


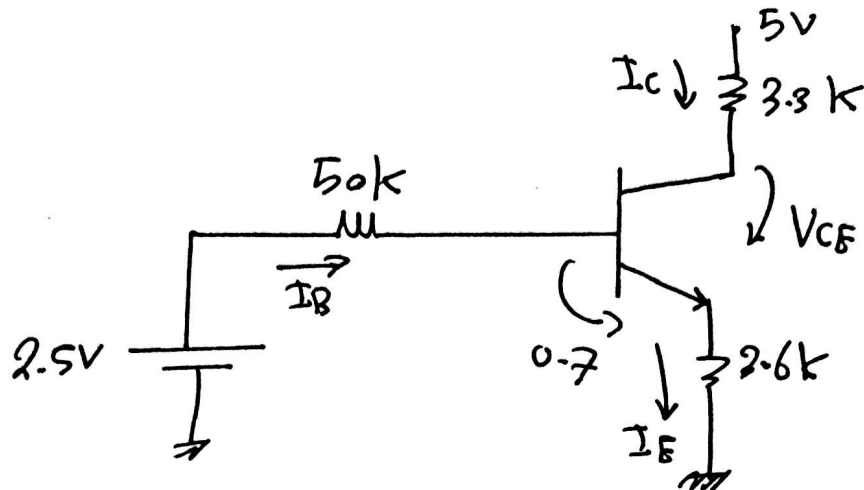
- 1) Find I_C , V_{CE} ?
- 2) Find A_v in Ratio and dB ?

Sohn DC circuit

1) Deactivate v_i

2) $\rightarrow \text{---} \rightarrow \text{---} \text{ } \text{O.C}$





I/P KVL

$$-2.5 + 50 I_B + 0.7 + 3.6 (58 I_B) = 0$$

$$I_B = 6.955 \mu A \Rightarrow I_C = 0.396 \text{ mA}$$

$$I_E = 0.4 \text{ mA}$$

O/P KVL

$$-5 + 3.3 * (0.396) + V_{CE} + 3.6 (0.4) = 0$$

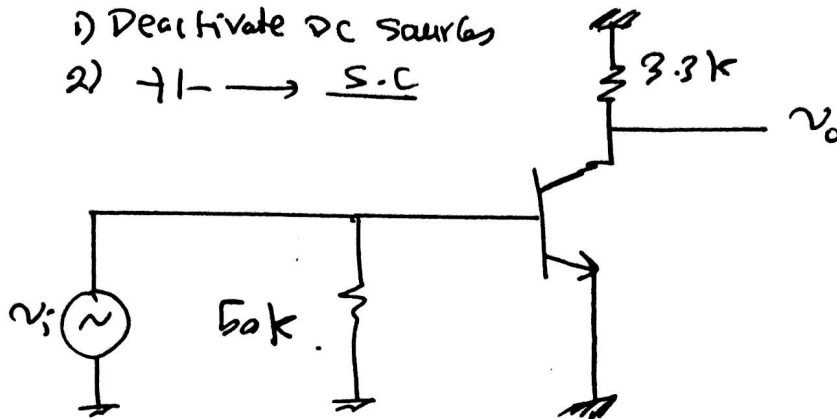
$$V_{CE} = 2.2582 \text{ Volt}$$

$$r_{\pi} = \beta \frac{V_T}{I_C} = 57 * \frac{26}{0.396} \approx 3.7 \text{ k}\Omega$$

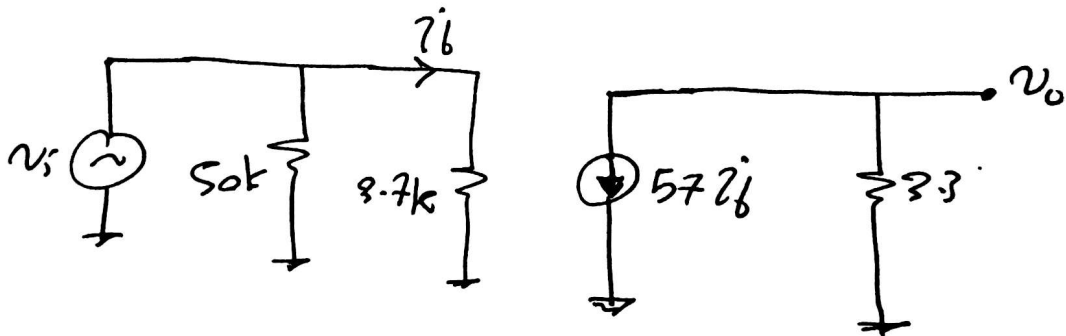
AC circuit:

1) Deactivate DC sources

2) \rightarrow S.C



* Small signal circuit:

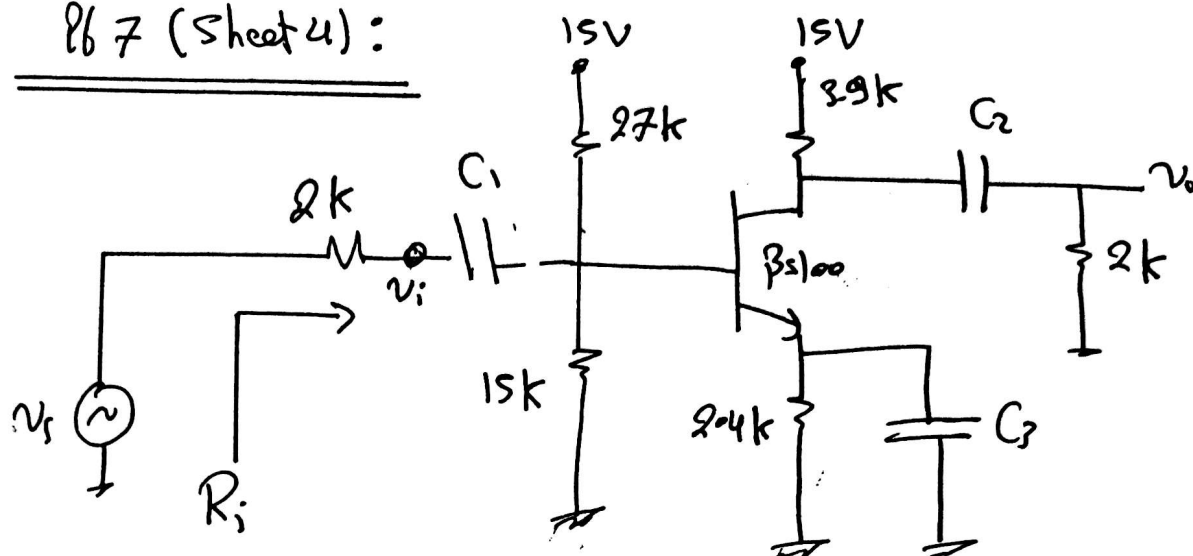


$$v_o = -3.3 \times 57 i_b$$

$$v_i = 3.7 i_b$$

$$A_v = \frac{v_o}{v_i} = -50.84, \quad A_v|_{dB} = 34.12 \text{ dB}$$

Pb 7 (Sheet 4):

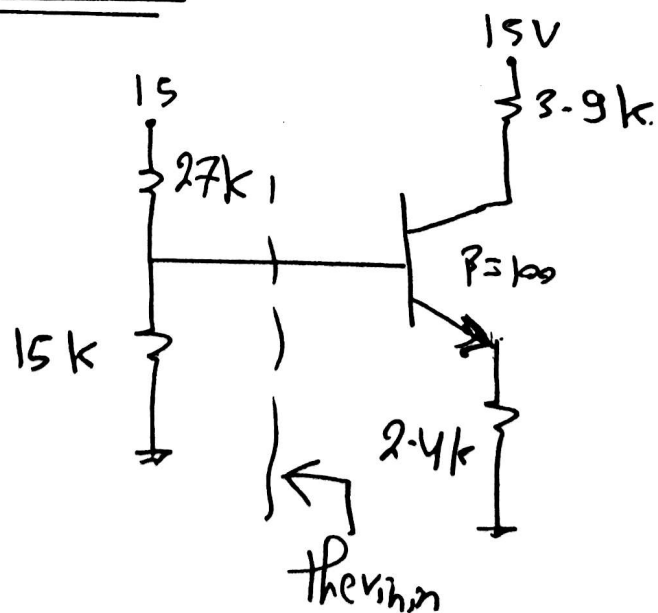


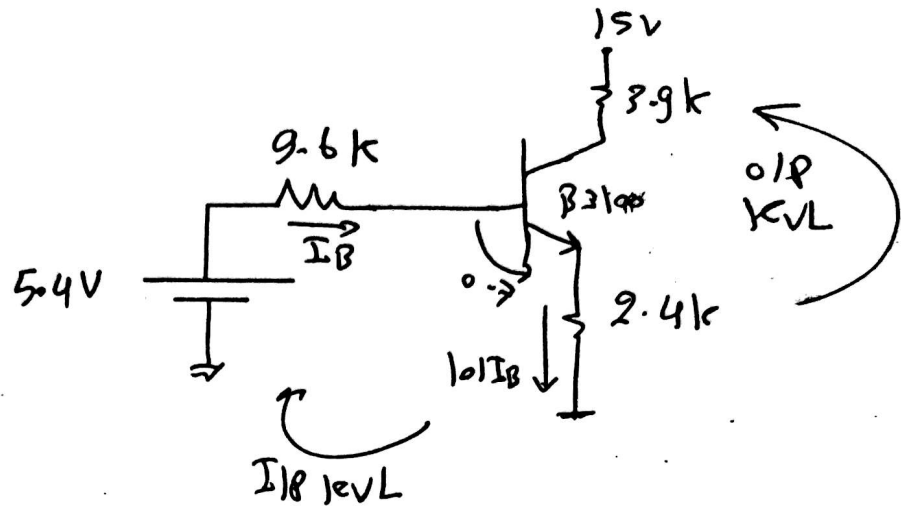
Find

- 1) R_i
- 2) $\frac{v_o}{v_i}$
- 3) $\frac{v_o}{v_s}$
- 4) $v_o = ?$ if $v_s = 1 \text{ mV}$

Soln

1) DC circuit





I_B KVL

$$-5.4 + 9.6 I_B + 0.7 + 101 I_B \times 2.4 = 0 \Rightarrow I_B = 18.65 \mu A$$

$$I_C = 1.865 \text{ mA}, I_E = 1.88 \text{ mA}$$

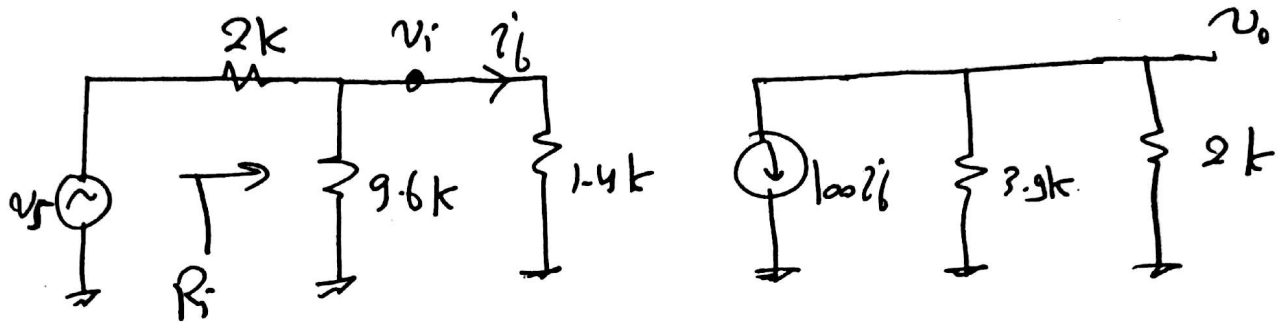
0/P KVL

$$-15 + 3.9 \times 1.865 + V_{CE} + 2.4 \times 1.88 = 0$$

$$V_{CE} = 3.2145 \text{ V}$$

$$r_{\pi} = \beta \frac{V_T}{I_C} = 100 \frac{26}{1.865} \approx 1.4 \text{ k}\Omega$$

* Small Signal Circuit !



$$R_i = 9.6 // 1.4 = 1.22 \text{ k}\Omega$$

$$v_o = -100 i_b * 3.9 // 2 = -132.2 i_b$$

$$v_i = 1.4 i_b$$

$$v_s = \left(i_b + \frac{1.4 i_b}{9.6} \right) * 2 + 1.4 i_b = 3.69 i_b$$

$$\frac{v_o}{v_i} = -94.4, \quad \frac{v_o}{v_s} = -35.8$$

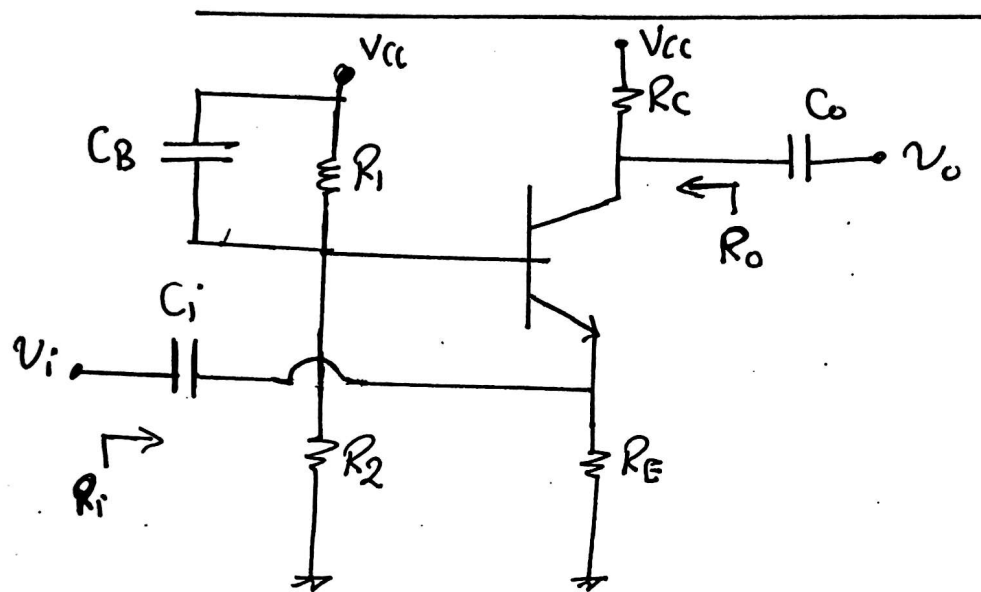
$$v_s = 1 \text{ mV} \Rightarrow v_o = -35.8 \text{ mV}$$

#

* BJT Common base amplifier :

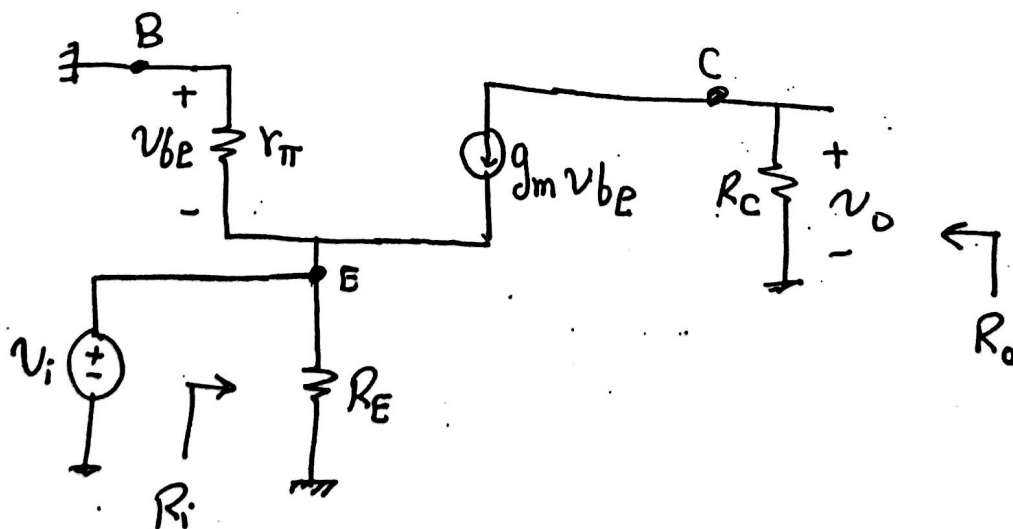
* Input at emitter and output at Collector

* Base is Common between input and output



Find A_v , A_i , R_i , R_o

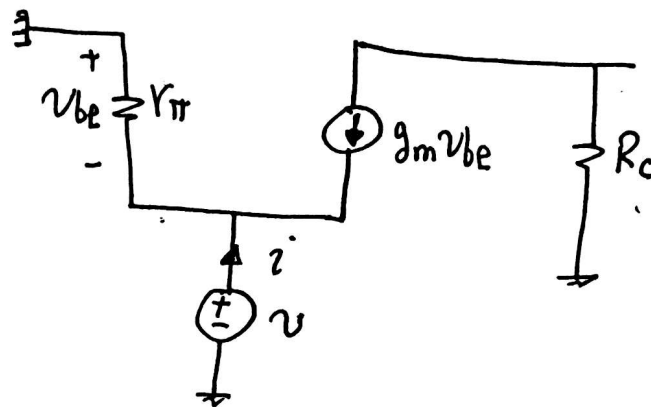
Soln



$$1) v_i = -v_{be} \quad , \quad v_o = -g_m R_c v_{be}$$

$$A_v = \frac{v_o}{v_i} = g_m R_c > 1$$

$$2) R_i = R_E \parallel R' \quad , \quad R' = ?$$



$$R' = \frac{v}{i} = \frac{-v_{be}}{-g_m v_{be} - \frac{1}{r_{\pi}} v_{be}} = \frac{1}{g_m + \frac{1}{r_{\pi}}}$$

$$R' = \frac{1}{g_m} \parallel r_{\pi}$$

$$R_i = R_E \parallel \frac{1}{g_m} \parallel r_{\pi} \quad , \quad \text{Note } r_{\pi} = \frac{\beta}{g_m}$$

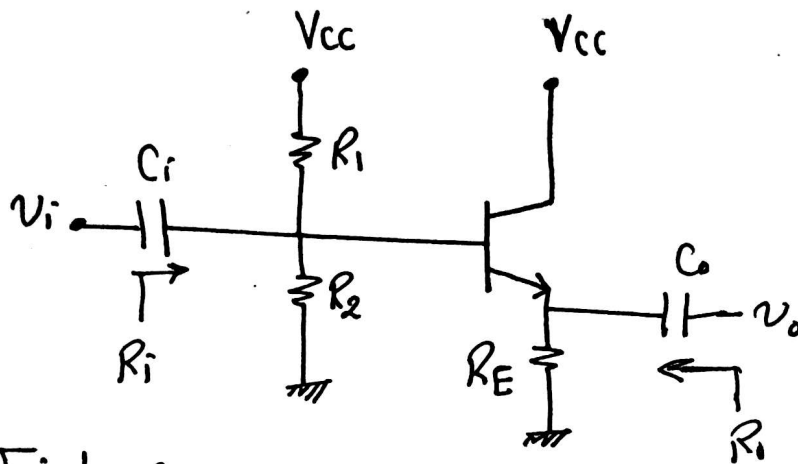
$$r_{\pi} \gg \frac{1}{g_m} \Rightarrow \frac{1}{g_m} \parallel r_{\pi} \approx \frac{1}{g_m}$$

$$R_i \approx R_E \parallel \frac{1}{g_m}, \quad R_o = R_c, \quad A_i = A_v \frac{R_i}{R_c} = \frac{g_m R_E}{1 + g_m R_E} \approx 1$$

* BJT Common Collector Amplifier :

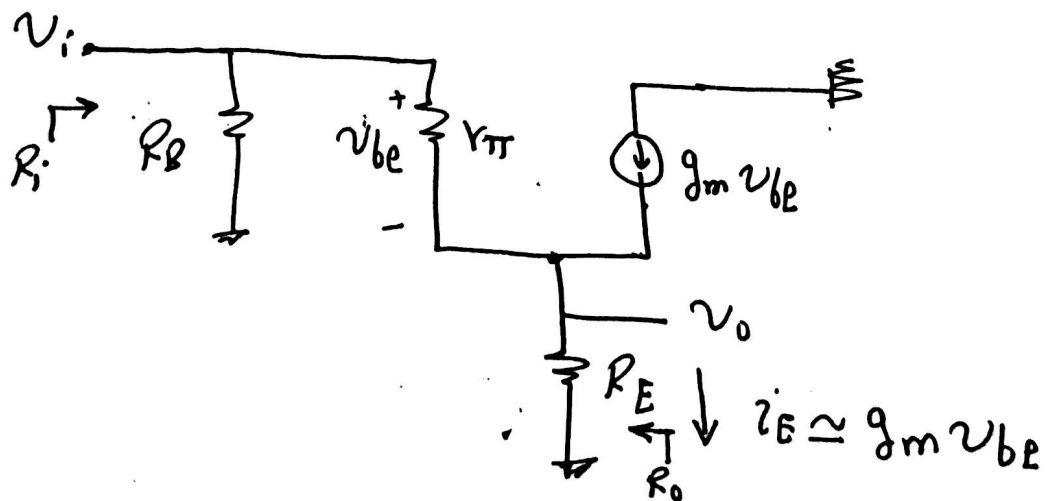
* Input at base & output at emitter

* Collector is common between i/p & o/p



Find A_v , A_i , R_i , R_o

Soln: $R_B = R_1 \parallel R_2$



$$V_i \approx v_{be} + g_m v_{be} R_E = (1 + g_m R_E) v_{be}$$

$$v_o \approx g_m R_E v_{be}$$

$$A_v \simeq \frac{g_m R_E}{1 + g_m R_E} < 1$$

$$\text{If } g_m R_E \gg 1 \Rightarrow A_v \simeq 1$$

$$R_i = R_B \parallel R' \quad , \quad R' = \frac{v}{i} = \frac{(1 + g_m R_E) v_{be}}{v_{be}/r_\pi}$$

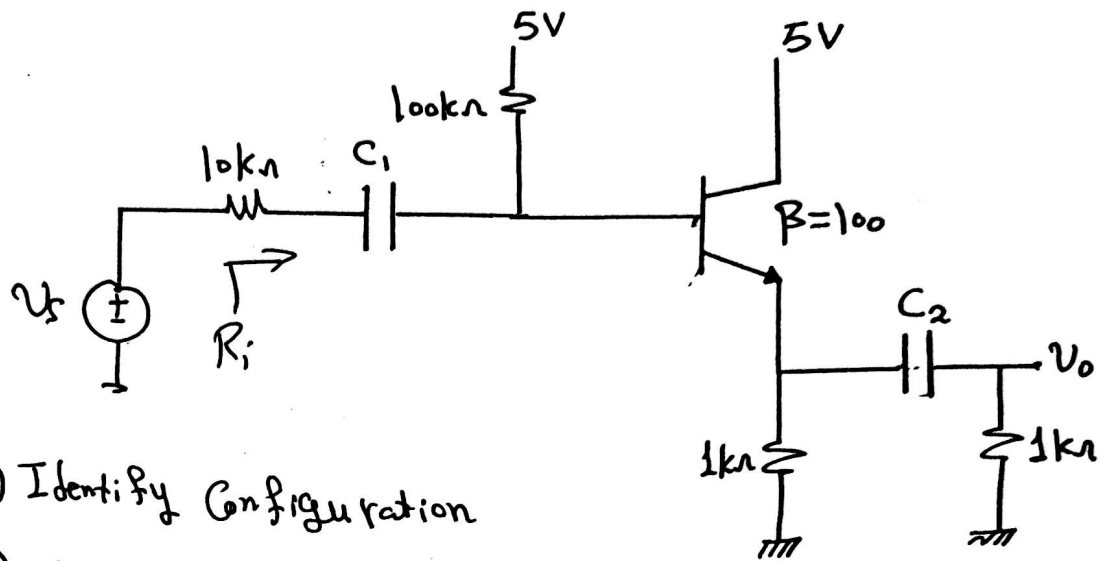
$$R' = r_\pi (1 + g_m R_E) = (r_\pi + \beta R_E)$$

$$R_i \simeq R_B \parallel [r_\pi + \beta R_E]$$

$$R_o = R_E \parallel r_\pi \parallel \frac{1}{g_m} \simeq R_E \parallel \frac{1}{g_m}$$

$$A_i = A_v * \frac{R_i}{R_E} \simeq \frac{R_B \parallel [r_\pi + \beta R_E]}{R_E} \simeq \frac{R_i}{R_E}$$

Pb₃ (Sheet 5) :



- 1) Identify Configuration
- 2) I_E , V_E and V_B
- 3) R_i
- 4) V_o/V_s

Soln

I/P at base

O/P at emitter

⇒ Common Collector
⇒ Emitter-follower

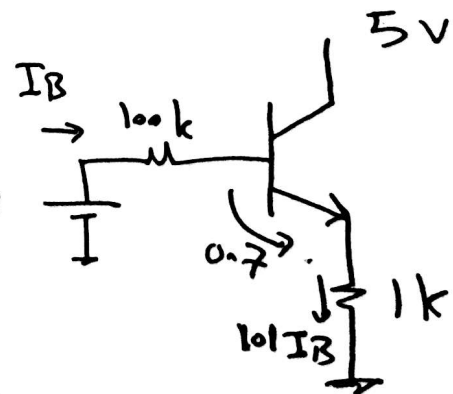
DC analysis

I/P KVL:

$$-5 + 100 I_B + 0.7 + 101 I_B = 0 \quad 5V$$

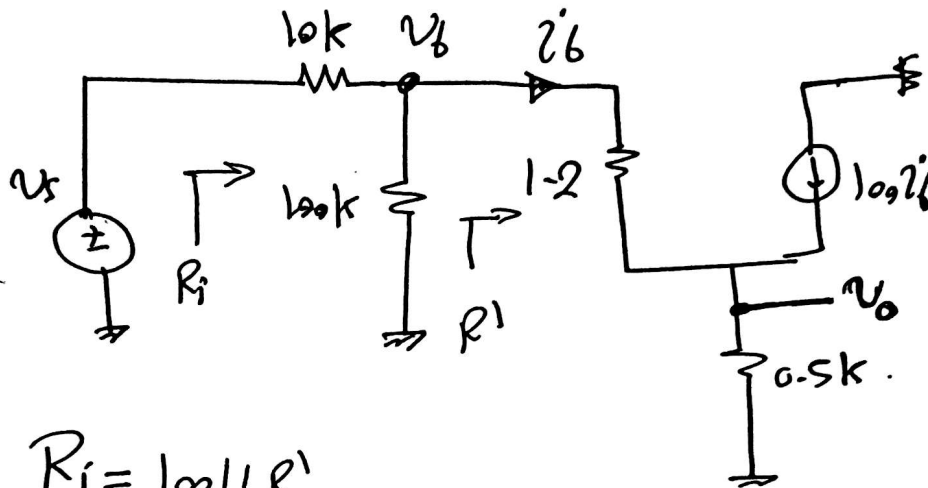
$$I_B = 0.0214 \text{ mA}$$

$$I_E = 2.16 \text{ mA}, \quad V_E = 2.16 \text{ V}, \quad V_B = 2.86 \text{ V}$$



$$r_{\pi} = \frac{V_T}{I_B} = \frac{26 \text{ mV}}{0.0214} = 1.2 \text{ k}\Omega$$

* Small signal model :



$$R_i = 100 \parallel R'$$

$$R' = \frac{v_b}{i_b} = \frac{1.2 i_b + 100 i_b \times 0.5}{i_b} = 51.8 \text{ k}\Omega$$

$$R_i = 100 \parallel 51.8 \approx 34 \text{ k}\Omega$$

$$v_o = 100 i_b \times 0.5 \rightarrow (1)$$

$$v_b = v_s \times \frac{R_i}{10 + R_i} = \frac{34}{44} v_s \Rightarrow v_s = \frac{44}{34} v_b \rightarrow (2)$$

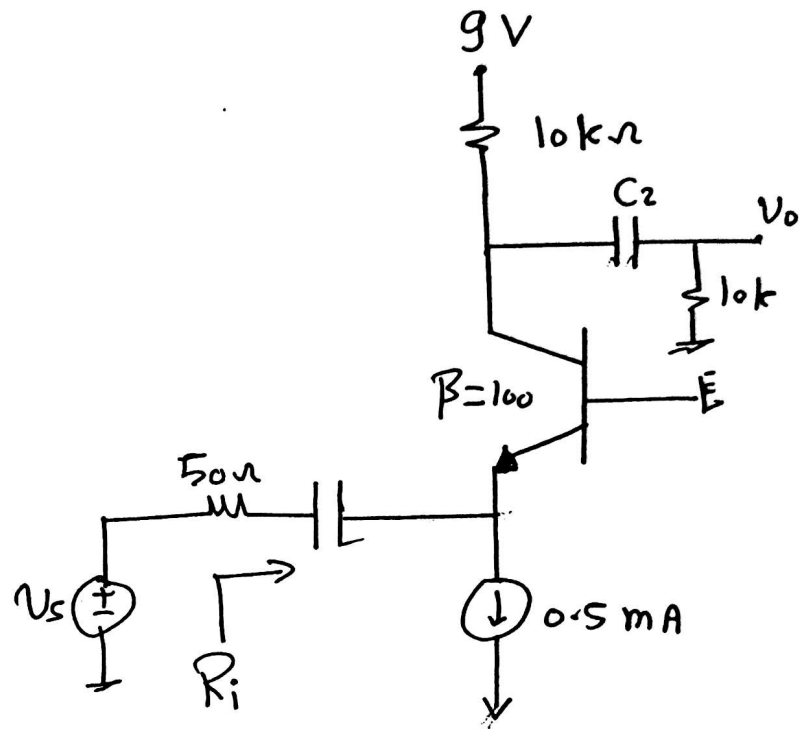
$$\frac{v_o}{v_s} = 100 \times 0.5 \times \frac{34}{44} \times \frac{i_b}{v_b} = 100 \times 0.5 \times \frac{34}{44} \times \frac{1}{51.8}$$

$$\frac{v_o}{v_s} = 0.75$$

Pb4 (Sheet 5)

* Find $R_i = ?$

* Find $V_o/v_{sig} = ?$



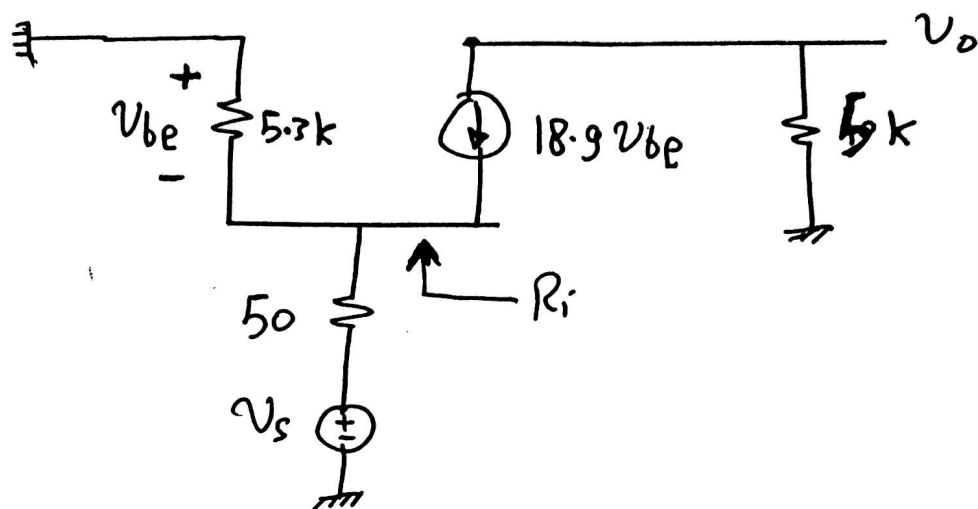
Soln

DC analysis $\rightarrow I_E = 0.5 \text{ mA}$

$$I_B = \frac{I_E}{\beta + 1} = \frac{0.5}{101} = 4.95 \mu\text{A}$$

$$r_{\pi} = \frac{V_T}{I_B} = \frac{26 \text{ mV}}{4.95 \mu\text{A}} = 5.3 \text{ k}\Omega$$

$$g_m = \frac{\beta}{r_{\pi}} = \frac{100}{5.3} = 18.9 \text{ mA/V}$$



$$R_i = 5.3 \parallel \frac{1}{18.9} \simeq \frac{1}{18.9} \text{ k} \simeq 52 \Omega$$

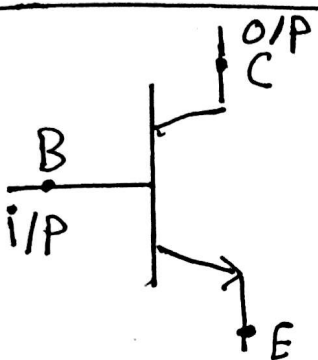
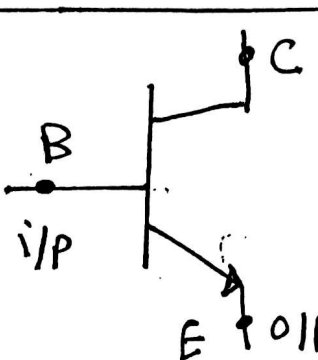
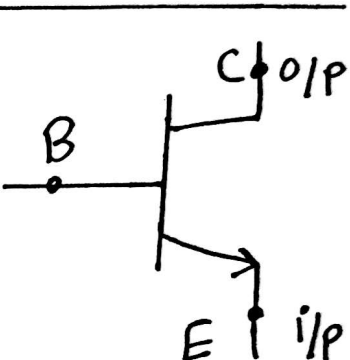
$$v_{be} = -v_s \times \frac{R_i}{50 + R_i} \rightarrow v_s \simeq -2 v_{be}$$

$$v_o = -18.9 v_{be} \times 5$$

$$\frac{v_o}{v_s} = \frac{-18.9 v_{be} \times 5}{-2 v_{be}} = 47.25 \quad \#$$

* Compare between Common emitter, Common collector
& Common-base.

(Emitter follower)

CE	CC ↑ (Emitter follower)	CB
		
$A_v \uparrow \uparrow$	$A_v \approx 1$	$A_v \uparrow \uparrow$
$R_i \sim k\Omega$ $R_o \sim k\Omega$	$R_i \sim 100k\Omega \uparrow$ $R_o \sim \Omega \downarrow$	$R_i \sim \Omega \downarrow$ $R_o \sim k\Omega$
Used as Voltage amplifier	Used as Buffer	Used as Current amplifier

Note Ideal CC →
Ideal Buffer

$$\begin{aligned} A_v &= 1 \\ R_i &= \infty \\ R_o &= \text{Zero} \end{aligned}$$